Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

1422

Issued April 10, 1912.

1
Ex6B
Cop. 3

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 248.

A. C. TRUE, Director.

EVAPORATION FROM IRRIGATED SOILS.

BY

SAMUEL FORTIER,
Chief of Irrigation Investigations,

AND

S. H. BECKETT,
Scientific Assistant.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

42

1422 Issued April 10, 1912.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 248.

A. C. TRUE, Director.

EVAPORATION FROM IRRIGATED SOILS.

BY

SAMUEL FORTIER,
Chief of Irrigation Investigations,

AND

S. H. BECKETT,
Scientific Assistant.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

OFFICE OF EXPERIMENT STATIONS.

A. C. True, Director.
E. W. Allen, Assistant Director.

IRRIGATION INVESTIGATIONS.

Samuel Fortier, chief.
R. P. Teele, assistant chief.

IRRIGATION ENGINEERS AND IRRIGATION MANAGERS.

A. P. Stover, irrigation engineer, in charge of work in Oregon.
C. E. Tait, irrigation engineer, in charge of work in southern California.
S. O. Jayne, irrigation manager, in charge of work in Washington.
Frank Adams, irrigation manager, in charge of work in California.
W. W. McLaughlin, irrigation engineer, in charge of work in Utah.
P. E. Fuller, irrigation engineer, in charge of work in Arizona and of power investigations.
W. L. Rockwell, irrigation manager, in charge of work in Texas.
D. H. Bark, irrigation engineer, in charge of work in Idaho.
Milo B. Williams, irrigation engineer, in charge of work in humid sections.
V. M. Cone, irrigation engineer, in charge of work in central California.
C. G. Haskell, irrigation engineer, in charge of rice investigations.
Fred G. Harden, scientific assistant.
R. D. Robertson, assistant irrigation engineer.
J. W. Longstreth, in charge of work in Kansas.
S. H. Beckett, scientific assistant.
Fred C. Scobey, irrigation engineer, in charge of work in Wyoming.
S. T. Harding, irrigation engineer, in charge of work in Montana and North Dakota.
H. W. Grunsky, irrigation engineer, in charge of work in eastern Oregon.
F. W. Stanley, irrigation engineer, in charge of work in Nebraska and South Dakota.

COLLABORATORS.

O. V. P. Stout, University of Nebraska, in charge of work in Nebraska.
Gordon H. True, University of Nevada, in charge of work in Nevada.
W. B. Gregory, Tulane University of Louisiana, in charge of rice irrigation in Louisiana and Texas.
F. L. Bixby, New Mexico Agricultural College, in charge of work in New Mexico.

IRRIGATION FARMERS.

John H. Gordon, R. G. Hemphill, W. H. Lauck, R. E. Mahoney, and John Krall, Jr.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., July 25, 1911.

Sir: I have the honor to transmit herewith a report on Evaporation from Irrigated Soils, prepared by Samuel Fortier, chief of irrigation investigations, and S. H. Beckett, scientific assistant, of this office. This report embodies the results of experiments carried on from 1908 to 1910, inclusive, at seven places in the arid region, to determine the amount of water lost by evaporation from irrigated soils treated in different ways. From 1903 to 1905, inclusive, experiments were conducted in California by the office of irrigation investigations to ascertain the amount of water lost by evaporation from irrigated soils. The results of these experiments were published in Bulletin 177 of this office. The experiments described in the present report were carried on for the purpose of checking the former results, of demonstrating the evaporation losses in colder and more elevated regions, and of broadening the scope of the investigations.

The time seems near when the reclamation of additional areas will depend chiefly upon the storage of flood waters, the pumping from underground supplies, and the utilization of waters now lost by evaporation, percolation, and seepage, or wasted in irrigation. This report should be of value not only to irrigators, but to the cultivators of the vast areas on which dry-farming methods must be practiced.

The office desires to thank the experiment stations of California, Montana, North Dakota, Idaho, New Mexico, Nevada, and Washington for their cooperation and assistance in conducting the experiments.

It is recommended that the report be published as a bulletin of this office.

Respectfully,
A. C. True,
Director.

Hon. Jas. Wilson,
Secretary of Agriculture.

CONTENTS.

Page.
Introduction ... 7
Equipment ... 8
Plan of experiments ... 9
Effects of soil mulches of different depths ... 11
  Results at Davis, Cal ... 11
  Results at Reno, Nev ... 15
  Results at Agricultural College, N. Mex ... 17
  Results at Bozeman, Mont ... 20
  Results at Wenatchee, Wash ... 24
  Summary of results ... 26
  Conclusions ... 29
Effects of cultivation to different depths ... 30
  Results at Sunnyside, Wash ... 31
  Results at Davis, Cal ... 33
  Results at Reno, Nev ... 37
  Results at Caldwell, Idaho ... 39
  Results at Agricultural College, N. Mex ... 42
  Results at Bozeman, Mont ... 44
  Results at Williston, N. Dak ... 46
  Summary and conclusions ... 48
Effects of shallow and deep furrow irrigation ... 51
  Results at Davis, Cal ... 52
  Results at Williston, N. Dak ... 55
  Results at Reno, Nev ... 57
  Results at Bozeman (Mont.), Agricultural College (N. Mex.), and Sunnyside (Wash) ... 59
  Summary of results at Reno, Nev., and Davis, Cal ... 60
Experiments of 1910 ... 62
  Results at Davis ... 62
Summary of results at all stations ... 67
Effect of temperature and wind velocity ... 69
General conclusions ... 74

ILLUSTRATIONS.

PLATES.

Page.
PLATE I. Fig. 1.—Experiment tract, Reno, Nev. Fig. 2.—Experiment tract, Agricultural College, N. Mex. 16
II. Fig. 1.—Experiment tract, Wenatchee, Wash. Fig. 2.—Experiment tract, Caldwell, Idaho 24

TEXT FIGURES.

FIG. 1. Design of tanks used in the experiments 9
2. Losses with mulches of different depths, Davis, Cal., 13
3. Losses with mulches of different depths, Davis, Cal 15
4. Losses with mulches of different depths, Reno, Nev 17
5. Losses with mulches of different depths, Agricultural College, N. Mex. 20
6. Losses with mulches of different depths, Bozeman, Mont 23
7. Losses with mulches of different depths, Wenatchee, Wash 26
8. Average losses at five stations, with mulches of different depths 27
9. Losses from cultivated and uncultivated tanks of soil, Sunnyside, Wash. 33
10. Losses from cultivated and uncultivated tanks of soil, Davis, Cal 36
11. Losses from cultivated and uncultivated tanks of soil, Reno, Nev 39
12. Losses from cultivated and uncultivated tanks of soil, Caldwell, Idaho 41
13. Losses from cultivated and uncultivated tanks of soil, Agricultural College, N. Mex 43
14. Losses from cultivated and uncultivated tanks of soil, Bozeman, Mont 45
15. Losses from cultivated and uncultivated tanks of soil, Williston, N. Dak 48
16. Average losses at six stations from cultivated and uncultivated tanks of soil 49
17. Losses from flooded and furrowed tanks of soil, Davis, Cal 54
18. Losses from flooded and furrowed tanks of soil at Williston, N. Dak 56
19. Losses from flooded and furrowed tanks of soil at Reno, Nev 59
20. Average losses from flooded and furrowed tanks at Davis, Cal. and Reno, Nev 61
21. Losses from tanks cultivated to different depths at Davis, Cal 66
22. Average weekly evaporation from water surface at seven stations 68
23. Mean temperature, average wind velocity, and evaporation from water surface at Davis, Cal 68
24. Mean hourly temperature, wind velocity, and evaporation from water surface, Davis, Cal 70
25. Evaporimeter 71
26. Evaporimeter record 73
27. Temperature of air, soil, and water, Davis, Cal 74

EVAPORATION FROM IRRIGATED SOILS.

INTRODUCTION.

With the approaching depletion of the water supply of the arid West, the question of unnecessary losses and wasteful use of water is rapidly rising into prominence. As development progresses, more people seek homes in towns and cities, and for such, water for domestic purposes becomes a necessity. There is at the same time an increasing use for manufacturing and mechanical purposes. The use of water for irrigation, however, creates the greatest of all demands upon the sources of supply. The necessity, therefore, of conserving water once in the soil through irrigation or rainfall, bears a vital relation to the general subject of conservation.

During the past 20 years, considerable data have been collected showing the extent of evaporation from water surfaces; yet this is a loss which human foresight and energy can not prevent. Considerable effort and attention, too, have been given the subject of seepage losses in canals, a type of waste which is entirely preventable. Important as this subject is to the individuals or groups directly affected thereby, these losses are minimized when considered from the point of view of the total water supply, for, ordinarily, seepage from one canal finds its way into another or back into the stream to be picked up again and utilized in other ways.

Water, if lost through evaporation from the soil, however, is permanently lost; yet this is a loss which is in a large measure under the control of human agencies. Thus irrigators who use wasteful quantities of water upon their fields and neglect cultivation simply because they are in position through court decrees or otherwise to do so, are measurably depleting the sources of supply. The purpose of this bulletin is not only to show the extent of evaporation losses from irrigated soils but the advantages to the individual of deep and thorough cultivation as a means of preventing wasteful use.

The relative importance of the inquiry is further shown by a comparison of areas. Throughout the arid region, and more particularly in the Rocky Mountain States, the area covered by water is quite small in comparison with the land area or even with the irrigated area. In the total area of Montana, for example, only 1 acre out of every 190 acres is covered with water and the ratio between the extent of water surface and of irrigated land is as 1 to 3.4.

In determining the extent and rate of evaporation from irrigated soils, this office has followed the plan adopted by hydraulic engineers in making similar determinations from water surfaces. By placing a known quantity of soil in a specially designed vessel, it is comparatively easy to determine the amount of water evaporated from its surface in a given time. Investigations of this kind were carried on in California during 1903 to 1905 and the results summarized in Bulletin 177 of this office. In planning similar work for 1908 and subsequent years, it was deemed advisable to broaden the scope of the investigation by carrying on the same kind of experiments in several Western States during the same season of the year. The records of this office giving the extent of evaporation from water surfaces show a wide difference in the results obtained in different localities of the same State. As an illustration, the annual evaporation at Berkeley, Cal., in 1905 was 41.6 inches, while at Tulare, Cal., it was 62.9 inches. It was thought that like differences might exist in the evaporation from irrigated soils.

The advantages derived from carrying on the same kind of experiments in States widely separated and varying greatly in altitude, temperature, soil, and climatic conditions are obvious. On the other hand, the work is rendered much more difficult to carry out in every essential detail. In dealing with so many agents working under different conditions, it is not easy to secure data that are both complete and comparable. In what follows there are omissions due to agents failing to secure the data. These omissions detract to some extent from the value of the bulletin.

In furtherance of the proposed work, cooperation was sought and obtained from a number of directors of western experiment stations who agreed to conduct the experiments as planned. Under this arrangement the necessary equipment was installed in the spring of 1908 at the experiment farm of the University of California located at Davis, at the experiment station of New Mexico located at Agricultural College, the experiment station at Bozeman, Mont., the experiment station at Reno, Nev., and in a private orchard near Wenatchee, Wash., as well as at the Sunnyside substation of the same State. The spring following, experiments were also started at the substation of the North Dakota Experiment Station at Williston, N. Dak., and at the Caldwell substation of the Idaho Experiment Station near Caldwell.

EQUIPMENT.

The equipment at each station consisted of eight galvanized-iron water-jacketed tanks. The inside tanks of each pair except those at the New Mexico station were 23½ inches in diameter, and the outer tanks 27 inches, thus allowing a free space of 1¾ inches on all sides between the tanks. Both inner and outer tanks were 47 inches deep and of the general form shown in figure 1.[1]

Two lugs were fastened on the inner tank so that an iron bail could be fastened in them and the tank raised and lowered by means of a differential pulley suspended from a derrick. Weighings were made either by means of platform scales or scales suspended from the differential pulley.

As auxiliary apparatus, each station was furnished with a thermometer shelter, maximum and minimum recording thermometers, soil and water thermometers, wet and dry bulb thermometers for determining humidities and vapor pressures, an anemometer, a rain gauge, and an evaporation tank with a hook gauge for measuring evaporation in inches. An attempt was made to secure as nearly as possible complete records of temperatures, wind velocities, rainfall, and the evaporation from a free water surface during the time of each experiment.

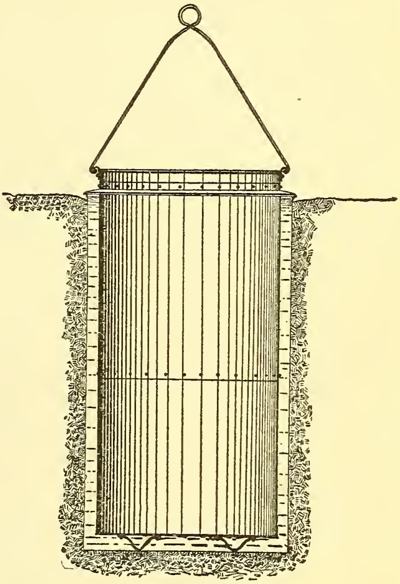

FIG. 1.—Design of tanks used in the experiments.

PLAN OF EXPERIMENTS.

In considering what experiments should be undertaken, the chief object kept in view was to secure results that would show the rate and extent of evaporation from irrigated soils. By making use of a sufficient number of tanks, it was found possible to show also the effect on evaporation of several cultural and irrigation methods of handling soil and applying water. Records were likewise collected for purposes of comparison, showing the extent and rate of evaporation from a free water surface. The cultural methods included the maintenance of dry soil mulches of different depths and shallow and deep cultivation. The irrigation methods included shallow and deep furrow irrigation and irrigation followed by cultivation.

In deciding upon the manner of conducting the experiments, the field rather than the laboratory was chosen. In working with small units in a laboratory the determinations can be more accurately made than with large units in a field. It is, however, impossible to maintain conditions in the laboratory as they exist in the open, subject as they are in the latter case to continuous and endless variations. The sunshine and fog, heat and wind, which act on the soil of a field, can not be made to act in anything like the same way on a sample of soil in a close room.

---

[1] The New Mexico tanks differed only in that the inner tanks were 27 inches in diameter and the outer ones 32 inches. In preparing the tables, etc., in this bulletin the losses from these larger tanks have been reduced to proportional losses from the smaller tanks.

The plan followed was to remove from a field about a half ton of soil, place it in a vessel as nearly as practicable in its natural position, and by periodical weighings ascertain the amount of moisture evaporated. Free exposure to sunshine, wind, and rain was easy to secure, but the placing of the soil in the vessel in the natural way and keeping its temperature equal to that of the adjacent soil was a harder task. Tests showed, however, that the temperature of the water in the annular space between the outer and inner tanks was about equal to the average temperature in the same depth of soil. Excavations were made for the tanks so that their tops were but slightly above the ground surface. As the soil was excavated to fill the tanks each vertical foot was kept separate and returned to the inner tank in 2-inch layers and tamped so that it duplicated as nearly as possible natural field conditions. Irrigation and cultivation were then practiced as the different experiments required and weighings were made of the inner tanks at least twice a week. The losses due to evaporation were first obtained in pounds and later reduced to their equivalent in inches in depth over the surface.

The summarized results of the data collected during the years 1908, 1909, and 1910 are grouped first in regard to the different experiments undertaken and second in regard to the localities where the experiments were performed. The more important results are shown in tables and diagrams, in both of which the evaporation from an irrigated soil undisturbed after the application of water is given and a comparison made between this loss and that from like irrigated soils upon which mulches were placed or which were subjected to cultural treatment.

There are three general types of experimentation carried on:

(1) Where an artificial mulch of varying depths composed of soil similar to that in the tanks was applied on top of the irrigated soil.

(2) Where the tanks of soil are given, as nearly as possible, a natural cultivation approximating that of actual field conditions; careful note being here taken of the amount of moisture lost in the period between irrigation and cultivation, the length of this period being varied in the different tests.

(3) A comparison of evaporation losses when water is applied in furrows of different depths and by the flooding process.

It will be observed that the methods followed do not accurately represent in every case either irrigation or cultural practice. At the same time every reasonable effort was made to make the experiments correspond to such practice as is followed by the most experienced orchardists in the West. In the opinion of the authors, the results of the data obtained do not differ in any essential degree from those that actually occur on an irrigated orchard or other cultivated and irrigated field.

EFFECT OF SOIL MULCHES OF DIFFERENT DEPTHS.

To determine the effect of soil mulches of different depths upon the evaporation from the soils, the following experiment was carried on at five of the stations during the year 1908. Tanks 1 and 2 were filled with soil to within 1 inch of the top; tanks 3 and 4 to within 4 inches of the top; tanks 5 and 6 to within 7 inches of the top; and tanks 7 and 8 to within 10 inches of the top. The tanks were then weighed and a sufficient amount of water to approximate a 6-inch irrigation was applied to each by the flooding method. The water was added from 5 to 10 gallon tanks and the flow so regulated that the entire surface of each tank was kept covered during the period of irrigation. After the water had entirely disappeared from the soil surface, fine, dry, granular soil mulches were added, as follows Tanks 1 and 2, no mulch; tanks 3 and 4, a 3-inch layer; tanks 5 and 6, a 6-inch layer; tanks 7 and 8, a 9-inch layer. Weighings were started immediately and continued semiweekly for a period of four weeks. The losses for each period were recorded and as nearly as possible a complete weather record was kept.

RESULTS AT DAVIS, CAL.

The site selected for the experiments was part of an open field on the university farm at Davis, located in the Sacramento Valley, 76 miles north of San Francisco and 13 miles west of Sacramento. The soil, which is typical of almost all the entire surrounding country, is a rich brown loam, which at a depth of 2½ or 3 feet gradually merges into a lighter, sandy subsoil. There are no intervening impervious strata between this subsoil and the water level. The experiment extended over two periods.

The first run was started June 10 and ended July 1. The tanks after being carefully filled were each given a 6-inch irrigation, and as soon as the water had disappeared from the surface of the soil the granular soil mulches were applied. During the experiment the maximum and minimum daily temperatures, the temperature of the water in an open tank, and the evaporation losses from a free-water surface were recorded. The maximum atmospheric temperatures ranged from 76° to 103° F., and the minimum temperatures from 39° to 59°, the greatest daily range being 45°. The daily maximum temperatures for the period averaged 88° and the daily minimum temperatures 49.7°. The temperature of the water at the surface varied with the atmospheric temperatures and ranged from 60° to 88°, the average for the period being 76°.[1] These records have been brought together in the following tables:

Mean maximum and minimum temperatures and the temperature of water in an open tank at Davis, Cal., June 10 to July 1, 1908.

Periods.	Mean maximum temperature.	Mean minimum temperature.	Mean maximum temperature of water.[1]
	°F.	*°F.*	*°F.*
June 10–13	90.3	48.3	84
June 13–17	83.0	49.7	82
June 17–20	83.3	47.3	81
June 20–24	83.0	45.7	77
June 24–27	91.3	48.0	85
June 27–July 1	97.2	58.2	83
Average, 21 days	88.0	49.7	81.8

[1] Taken at the surface at 2 p. m.

Evaporation from free-water surface and from tanks with different depth mulches at Davis, Cal., June 10 to July 1, 1908 (6 inches of irrigation water applied).

Periods.	Loss from water surface.	Loss from soil.							
		No mulch, tanks 1 and 2.		3-inch mulch, tanks 3 and 4.		6-inch mulch, tanks 5 and 6.		9-inch mulch, tanks 7 and 8.	
Average weight of tanks June 10, pounds	....	1,206		1,180.7		1,118.7		1,091.5	
Average loss:	*Inches.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*
June 10–13	1.07	10.75	11.4	0.50	0.5	0.0	0.0	0.00	0.00
June 13–17	1.44	3.50	3.7	.50	.5	.5	.5	.00	.00
June 17–20	1.19	1.50	1.6	.50	.5	.5	.5	.00	.00
June 20–24	1.35	1.50	1.6	.75	.8	[1] —.5	—.5	.00	.00
June 24–27	1.66	2.25	2.4	2.00	2.1	1.0	1.1	.25	.27
June 27–July 1	1.56	1.75	1.9	.75	.8	.5	.5	.25	.27
Total loss, 21 days	8.27	21.25	22.6	5.00	5.2	2.0	2.1	.50	.54
Equivalent loss in inches	....	1.35		.32		.13		.03	

[1] Due to slight inaccuracies in weighing.

The total losses in inches and the percentage of loss by three and four day periods for the different sets of tanks are also shown graphically in figure 2.

The following facts are derived from the foregoing tables:

(1) The loss of water from the unmulched surfaces was only 1.35 inches as compared with 8.27 inches from the free-water surface.

(2) The loss from the unmulched surfaces was equivalent to 22.6 per cent of the total amount of water used in irrigation.

(3) The losses when 3, 6, and 9 inch mulches were used were only 5.2, 2.1, and 0.54 per cent, respectively, of the total amount of water used.

---

[1] Readings were made at 8 a. m., 2 p. m., and 5 p. m. This average is an average of the three readings.

The increased evaporation loss from the free-water surface for the three days, June 24–27, is accompanied by a corresponding increase in the evaporation from the soil. Both increases were due to dry north winds during those three days. The losses for the rest of the period are quite uniform, decreasing in the case of the unmulched soil and increasing in the case of the mulched soil toward the end of the experiment as the moisture gradually worked its way upward through the mulches.

A second trial was made at the same place and in the same manner and with the same equipment, beginning September 1 and extending over a period of 32 days. Semiweekly weighings were made from September 1 to 15, then, owing to the differential pulley being out of order, no weighing was made until the morning of the thirty-third day.

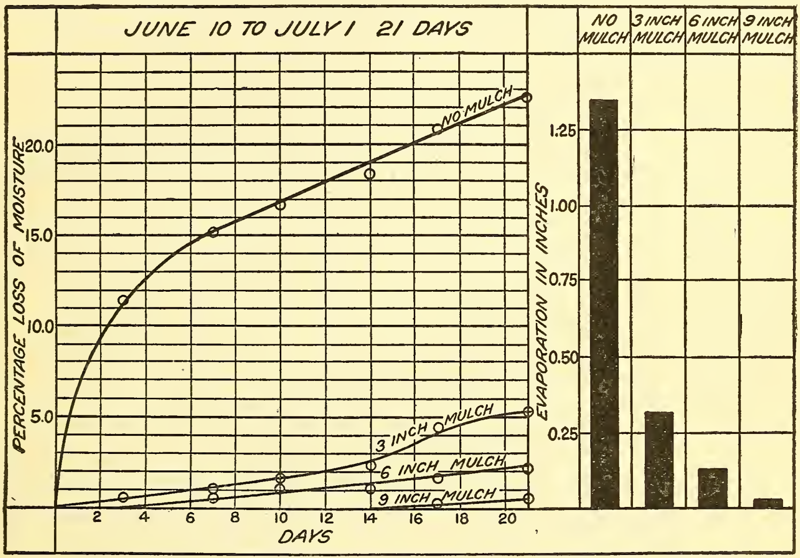

FIG. 2.—Evaporation losses from tanks with soil protected with mulches of different depths at Davis, Cal., June 10 to July 1, 1908.

The temperatures did not differ materially from those of the June experiment, the absolute maximum being 103° F. and the absolute minimum 42°, with the greatest daily range 55°. The maximum temperature averaged 88.4° and the minimum 50.7° for the period. An anemometer and soil thermometer had been added to the apparatus, and the maximum soil temperatures, taken at a depth of 6 inches, and mean wind velocities are included in the following tables, together with the atmospheric and water temperatures and the evaporation losses from free-water surface and unmulched and mulched soil surfaces.

Mean maximum and minimum temperatures, mean maximum soil and water temperature, and mean wind velocity at Davis, Cal., Sept. 1 to Oct. 3, 1908.

Periods.	Mean maximum temperature.	Mean minimum temperature.	Mean maximum soil temperature.[1]	Mean maximum water temperature.	Mean wind velocity per hour.
	°F.	*°F.*	*°F.*	*°F.*	*Miles.*
Sept. 1-4	99.7	53.0	79.5	83.3	7.0
Sept. 4-8	93.5	53.0	79.5	80.5	8.5
Sept. 8-11	91.0	50.0	77.6	78.0	9.1
Sept. 11-15	92.7	53.0	79.0	81.7	7.3
Sept. 15-Oct. 3	84.0	49.2	73.7	74.0	12.8
Average, 32 days	85.3	50.9	76.0	77.0	10.7

[1] Taken 6 inches below surface.

Evaporation from free-water surface and from tanks with mulches of different depths at Davis, Cal., Sept. 1 to Oct. 3, 1908 (6 inches of irrigation water applied).

Periods.	Loss from water surface.	Loss from soil.							
		No mulch, tanks 1 and 2.		3-inch mulch, tanks 3 and 4.		6-inch mulch, tanks 5 and 6.		9-inch mulch, tanks 7 and 8.	
Average weight of tanks Sept. 1, pounds	....	1,104.7		1,090		1,082		1,085.2	
Average loss:	*Inches.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*
Sept. 1-4	1.07	16.75	17.8	1.75	1.9	0.00	0.0	0.00	0.0
Sept. 4-8	1.40	4.50	4.8	.75	.8	.25	.3	[1] —.50	—.5
Sept. 8-11	.89	3.00	3.2	2.25	2.4	.75	.8	[1] —.25	—.3
Sept. 11-15	1.23	1.50	1.6	2.50	2.7	.00	.0	.00	.0
Sept. 15-Oct. 3	5.60	8.00	8.5	7.00	7.4	4.75	5.0	2.25	2.4
Total loss, 32 days	10.19	33.75	35.9	14.25	15.2	5.75	6.1	1.50	1.60
Equivalent loss, in inches	....	2.15		.91		.39		.10	

[1] Due to slight inaccuracies in weighing.

The total losses in inches and the percentage of loss by three and four day periods, September 1 to 22, is also shown graphically in figure 3. In compiling the data for this figure it was assumed that the losses from the fourteenth to the twenty-second day were uniform, the differential pulley being out of order between those dates, as already explained.

The results of this experiment follow very closely those obtained from June 10 to July 1. In all cases greater losses are recorded in the September experiment. This was due to an increase in the percentage of moisture in the soil over that in June and to the longer period over which the experiment extended. The unmulched surfaces show a loss of 2.15 inches of water, while the evaporation from a free-water surface amounted to 10.19 inches. It will also be noticed that 49.5 per cent of the loss from the unmulched surface occurred during the first three days after irrigation. The 3-inch mulch lost an equivalent of 0.91 inch of water, or only 42 per cent of the loss from the unmulched surfaces. There appears to be quite a variation between the 6 and 9 inch mulches, the 6-inch losing 0.39 inch and the

9-inch only 0.1 inch of water, being but 18 and 4.6 per cent, respectively, of the loss from the unmulched surfaces. This variation is due to the length of the experiment, as the weights show that most of the loss from the 6-inch mulch occurred in the last two weeks, the moisture having worked upward through the mulch to the surface. At the end of the test the moisture in the 9-inch mulch was still several inches from the surface.

RESULTS AT RENO, NEV.

The site chosen was on the State agricultural farm near Reno, on a spot free from obstruction to sun, wind, and rain, and inclosed by a woven-wire fence. The location, which has an altitude of 4,490 feet, is one typical of a large amount of irrigated land in Nevada, including that covered by the United States reclamation project. The soil is a sandy alluvial loam, intermixed with a considerable proportion of sand and small rock fragments, and is typical of the locality around Reno. (Pl. I, fig. 1.)

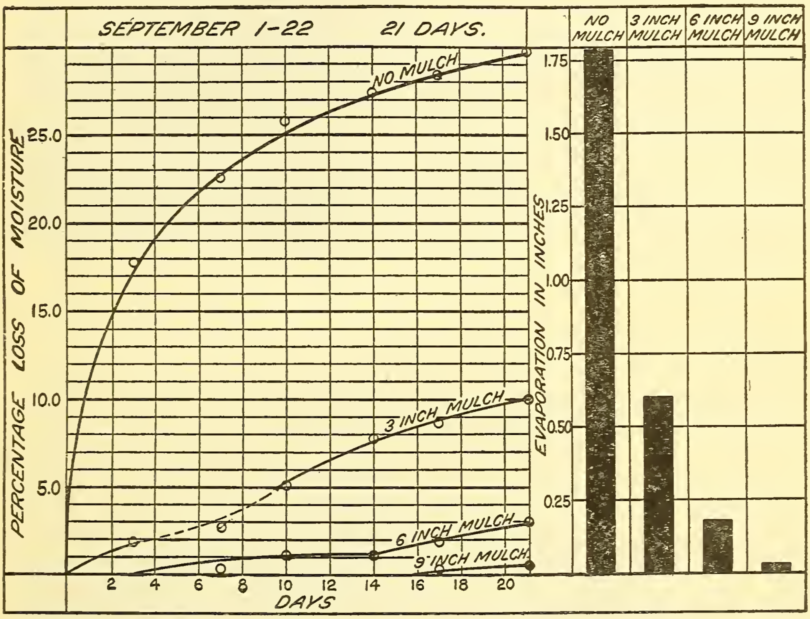

FIG. 3.—Evaporation losses from tanks with soil protected with mulches of different depths at Davis, Cal., September 1-22, 1908.

The tanks were filled June 9, soil samples being taken, from which moisture determinations were later made. All tanks were given a 6-inch irrigation and the soil mulches applied immediately after the water had disappeared. Owing to the scales being out of adjustment the weighings of the first three days had to be discarded and the experiment was really begun three days after the irrigation. September 1 the tanks were refilled with fresh soil and the experiment repeated. During the period of the experiment there was a total of 0.3 inch precipitation, a part of which fell during four days. The apparent evaporation from the tanks was corrected in each case by adding the precipitation to the loss in weight, thus giving the actual evaporation loss. Unfortunately, no record was taken of temperatures or wind velocities.

In the following table the evaporation losses for the two periods have been combined and average results are given:

Average evaporation from soils protected by different depths of soil mulches at Reno, Nev., June 9 to 30 and Sept. 1 to 22, 1908 (6 inches of irrigation water applied).

	Days.	Loss from water surface.[1]	Loss from soil.							
			No mulch, tanks 1 and 2.		3-inch mulch, tanks 3 and 4.		6-inch mulch, tanks 5 and 6.		9-inch mulch, tanks 7 and 8.	
Average weight of tanks June 9, pounds	....	....	1,265.2		1,261.2		1,283.1		1,263.8	
Average loss:		*Inches.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds*	*Per ct.*
First period	3	0.00	8.00	8.5	2.75	2.9	0.00	0.0	0.00	0.0
Second period	4	1.53	4.30	4.6	2.80	3.0	2.50	2.7	2.00	2.1
Third period	3	.00	3.10	3.3	2.10	2.2	.40	.4	.25	.3
Fourth period	4	1.60	2.10	2.2	1.90	2.0	.20	.2	.00	.0
Fifth period	3	.00	1.50	1.6	.80	.8	.50	.5	.00	.0
Sixth period	4	1.55	3.20	3.4	3.50	3.7	2.10	2.2	.50	.5
Total loss	21	4.68	22.20	23.6	13.85	14.6	5.70	6.0	2.75	2.9
Equivalent loss in inches	....	....	1.41		.88		.36		.17	

[1] Weighings taken but once a week.

The evaporation losses shown are comparatively light, but this is to be expected, as the experiment extends over a period of only three weeks and the evaporation losses from a free-water surface are very light, showing that moderate temperatures and wind velocities must have prevailed.

The unmulched surfaces show a loss during the three weeks of 1.41 inches, which is 23.6 per cent of the 6 inches applied, as against an average loss of 4.68 inches from a free-water surface for the same period. The 3-inch mulch gave a loss of 0.88 inch, or 14.6 per cent of the 6 inches applied, and is only 62.4 per cent of the loss from the unmulched surface. The loss with the 6-inch mulch was 0.36 inch and that with the 9-inch mulch 0.17 inch, being only 25.5 per cent and 12 per cent, respectively, of the loss from the bare surfaces. Practically all of the variation between the losses with the 6 and 9 inch mulches came in the last four days of the experiment.

Moisture determinations, made by exposing the soil in thin layers to air and sunshine before irrigation at the beginning of the September experiment, gave the following results.

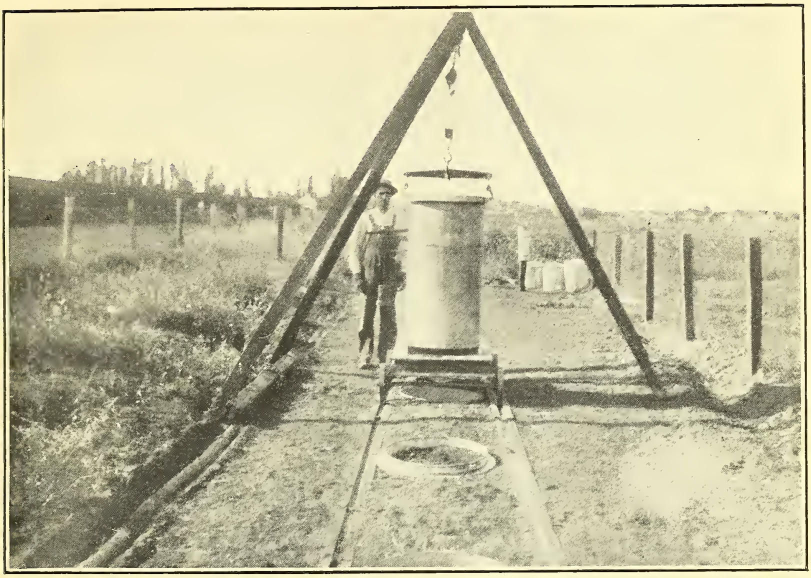

FIG. 1.—EXPERIMENT TRACT, RENO, NEV.

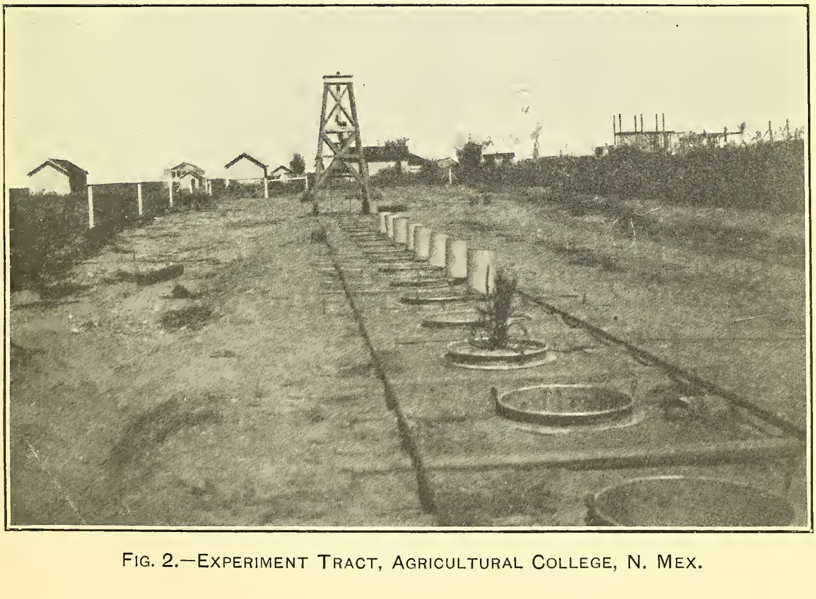

FIG. 2.—EXPERIMENT TRACT, AGRICULTURAL COLLEGE, N. MEX.

Percentage of free-moisture content of tanks at the beginning of the September experiment.

Depths.	Tanks 1 and 2.	Tanks 3 and 4.	Tanks 5 and 6.	Tanks 7 and 8.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1 foot	9.44	8.68	12.24	9.24
2 feet	10.92	12.40	11.94	12.40
3 feet	11.26	11.84	12.50	12.00
4 feet	11.80	11.54	10.42	12.50
Average	10.85	11.12	11.78	11.53

This shows a very even distribution of moisture through the soil, with no indication of free water settling in the bottom of the tanks.

Figure 4 shows graphically the relation between the amounts of the evaporation in the different sets of tanks.

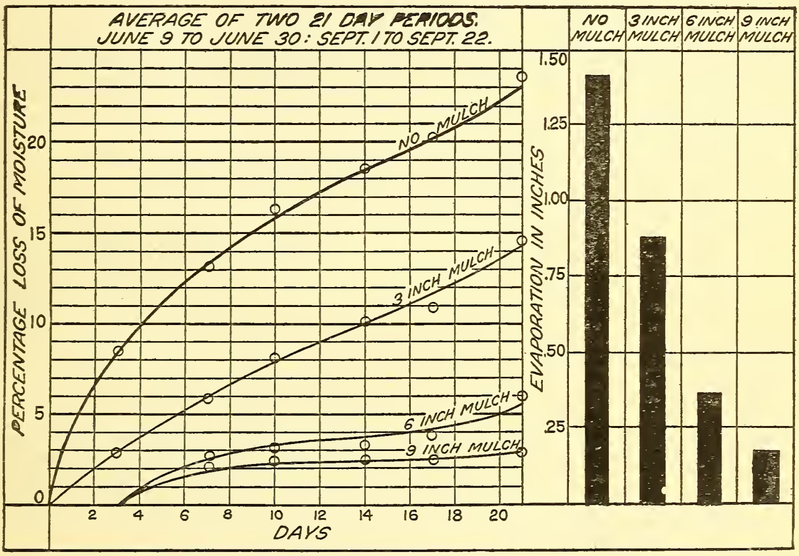

FIG. 4.—Average evaporation losses from tanks with soil protected with mulches of different depths at Reno, Nev., June 9-30 and September 1-22, 1908.

RESULTS AT AGRICULTURAL COLLEGE, N. MEX.

The New Mexico Experiment Station is located in the valley of the Rio Grande, a little west of the center of the State and about 20 miles north of its southern boundary. The soil of the tract is a sandy loam with gravel layers interspersed and some gravel intermixed. It is an alluvial deposit derived from the wash of the bench land to the east. In the fine material there is more silt than clay, and there is practically no distinction between soil and subsoil. The soil conditions and the apparatus used are shown on Plate I, figure 2.

The characteristic features of the climate of the locality are a high daily maximum temperature, which gives a fairly high mean temperature, a high percentage of clear days, a low relative humidity, a mean annual rainfall of 8.8 inches, and a fairly high-wind velocity. These conditions favor rapid evaporation from water and soil surfaces.

The experiment was started on September 25, 1908, and was repeated six times, the last ending March 2, 1909. No measured amount of water was applied in the irrigations, enough being added each time to thoroughly saturate the soil. Unfortunately soil samples for moisture determinations were not taken in any of these tests, and no idea of the original moisture content of the soil can be obtained. The heavy losses from the unmulched soil surfaces, however, show that the soil in each case must have been thoroughly moistened. During three of the trials 0.5 inch or more of rain fell and entirely spoiled the effect of the mulches. The results for these tests have been excluded in the following tables. The period showing the best results was from February 5 to March 2, during which only 0.09 inch of rain fell. The climatological conditions and losses from the several tanks by three and four day periods are shown in the following tables for this period:

Mean temperature, relative humidity, wind velocity, and rainfall at Agricultural College, N. Mex., Feb. 5 to Mar. 2, 1909.

Periods.	Mean temperature.	Mean relative humidity.	Mean wind velocity per hour.	Rainfall.
	°F.	*Per cent.*	*Miles.*	*Inch.*
Feb. 5-9	46	43	10.6	....
Feb. 9-12	45	36	5.8	....
Feb. 12-16	41	46	8.4	0.03
Feb. 16-19	51	30	11.5	....
Feb. 19-23	41	49	13.6	.06
Feb. 23-26	37	45	4.2	....
Feb. 26 to Mar. 2	48	37	5.1	....
Average, 25 days	44.1	41	8.6	....

Evaporation from free-water surface and from tanks with mulches of different depths at Agricultural College, N. Mex., Feb. 5 to Mar. 2, 1909.[1]

Periods.	Loss from water surface.	Loss from soil.							
		No mulch.		3-inch mulch.		6-inch mulch.		9-inch mulch.	
		Tank 1.	Tank 2.	Tank 3.	Tank 4.	Tank 5.	Tank 6.	Tank 7.	Tank 8.
Average loss:	*Inches.*	*Pounds.*	*Pounds*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Feb. 5-9	1.00	8.6	7.9	4.5	3.5	0.0	0.6	1.2	0.6
Feb. 9-12	.90	4.0	5.1	.0	.0	.0	.0	.0	.0
Feb. 12-16	.98	6.7	6.0	.4	2.6	.4	.4	.4	.4
Feb. 16-19	.55	7.9	6.9	1.7	1.7	.0	2.3	1.2	.6
Feb. 19-23	.66	.0	.0	.0	.0	.0	.0	.0	.0
Feb. 23-26	.80	2.9	3.4	1.7	1.7	.0	.0	.0	.0
Feb. 26 to Mar. 2	1.05	1.2	3.4	.0	1.2	1.2	1.2	.6	.0
Total loss, 25 days	5.94	31.3	32.7	8.3	10.7	1.6	4.5	3.4	1.6
Equivalent of average loss in inches	....	2.04		.61		.19		.16	

---

[1] The inner tanks were 27 inches in diameter. For uniformity the losses in this and other tables for New Mexico are the proportional losses for tanks 23½ inches in diameter.

The unmulched tanks showed an average total loss of 32 pounds, equivalent to 2.04 inches of water. Twenty-six per cent of the loss occurred in the first four days after irrigation. The 3, 6, and 9 inch mulches showed average losses of 0.61, 0.19, and 0.16 inch of water, respectively. In the case of the 3-inch mulch 42 per cent of the total loss occurred in the first four days, while the losses with 6 and 9 inch mulches seem to be more or less evenly distributed. The loss from the unmulched surfaces was 34.4 per cent of that from a free-water surface. Seventy per cent of this heavy loss was saved by a 3-inch mulch, 90 per cent by a 6-inch mulch, and 92.3 per cent by a 9-inch mulch.

Similar tables showing the averages for the three following periods, January 8 to February 2, February 5 to March 2, and March 5 to March 30, are given below:

Average mean temperature, relative humidity, wind velocity, and average rainfall by three and four day periods at Agricultural College, N. Mex. (Jan. 8 to Feb. 2, Feb. 5 to Mar. 2, and Mar. 5 to Mar. 30, 1909).

Periods.	Days.	Mean temperature.	Mean relative humidity.	Mean wind velocity per hour.	Rainfall.
		°F.	*Per cent.*	*Miles.*	*Inch.*
First	4	46	36	7.2	0.00
Second	3	43	51	7.5	.85
Third	4	43	47	6.1	.03
Fourth	3	52	33	10.1	.06
Fifth	4	48	38	9.3	.06
Sixth	3	47	43	7.9	.05
Seventh	4	52	40	6.6	.00
Average	25	47.2	41	7.8	....

Average evaporation from free-water surface and from tanks with mulches of different depths, at Agricultural College, N. Mex., by three and four day periods (Jan. 8 to Feb. 2, Feb. 5 to Mar. 2, and Mar. 5 to Mar. 30, 1909).

Periods.	Days.	Loss from water surface.	Loss from soil.							
			No mulch.		3-inch mulch.		6-inch mulch.		9-inch mulch.	
			Tank 1.	Tank 2.	Tank 3.	Tank 4.	Tank 5.	Tank 6.	Tank 7.	Tank 8.
		Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First	4	0.82	9.1	9.1	3.1	2.1	0.3	1.0	1.0	0.8
Second	3	.45	4.2	3.6	2.3	2.0	1.3	.8	1.1	1.2
Third	4	.68	5.1	4.8	1.0	2.3	1.0	.5	1.0	1.2
Fourth	3	.63	7.1	6.9	2.7	1.5	1.0	1.7	1.2	1.2
Fifth	4	.77	4.4	5.5	.3	.6	.2	1.9	.2	.0
Sixth	3	.78	2.3	2.5	1.2	.9	.2	.6	.8	.6
Seventh	4	.54	2.1	2.5	1.3	1.0	1.3	1.4	1.5	.4
Total loss	25	4.67	34.3	34.9	11.9	10.4	5.3	7.9	6.8	5.4
Equivalent loss in inches	....	....	2.20		.71		.42		.39	

These average results covering approximately a period of three months are almost identical with those obtained during the month of

February. The loss from an unmulched surface averaged 2.20 inches of water, or 47 per cent of the total amount evaporated from a free-water surface. Of this, 26.3 per cent was lost in the first four days. The 3-inch mulch shows a loss of 0.71 inch of water, or a saving of 67.7 per cent of the amount lost from an unmulched surface. Between the 6 and 9 inch mulches there seems to be but little choice, the 6-inch mulch, showing a saving of 81 per cent, and the 9-inch showing a saving of 82 per cent, the losses in each being small and evenly distributed throughout the experiment.

The weather records show that very uniform conditions prevailed throughout, and nowhere is the variation large enough to produce a noticeable effect on the evaporation losses. Figure 5 shows graphically the relative evaporation losses reduced to inches. As no definite amount of water was applied it was not possible to show the percentages of the losses graphically.

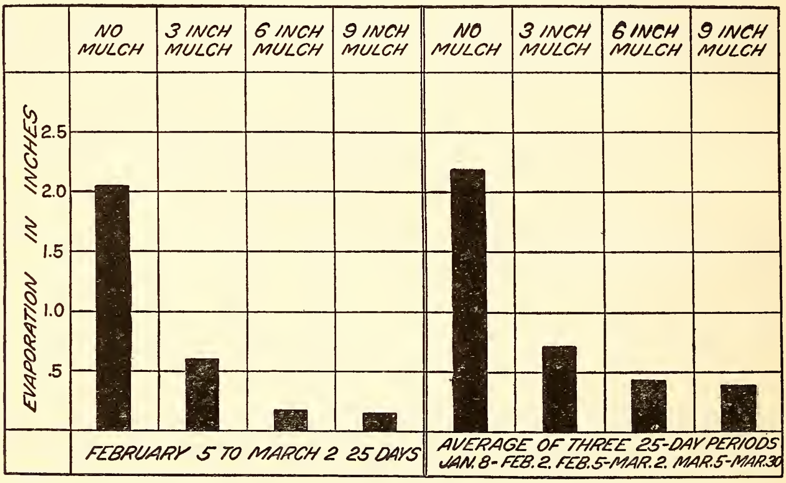

FIG. 5.—Average evaporation losses from tanks with soil protected with mulches of different depths at Agricultural College, N. Mex., January 8 to February 2, February 5 to March 2, and March 5-30, 1908.

RESULTS AT BOZEMAN, MONT.

The site chosen for the experiments in Montana was at Bozeman in the Gallatin Valley. This valley covers nearly 330 square miles, located in the south central portion of the State. It was at one time the bed of an old lake and the soil is naturally rich in humus and plant foods of all kinds. The soil is a silty loam with a heavy loam underneath, and the entire valley seems to be underlain with a stratum of sand and gravel at a depth of 1 to 6 feet below the surface.

A small plat upon which to conduct the experiments was set apart at the State experiment station, and the experiments were carried on in the usual way with apparatus similar to that described in the other experiments.

A record of the temperatures of the air, soil, and water, the rainfall and the evaporation was taken during the period of the experiment. No record was taken of the wind velocities. As this is one of the important factors in evaporation losses, the following table showing the average velocity of the wind at Bozeman during 1905, 1906, and 1907 has been compiled from the Weather Bureau reports:

Average velocity of wind in miles per hour at Bozeman, Mont., 1905, 1906, and 1807.

Month.	Maximum.	Minimum.	Average.
	Miles.	*Miles.*	*Miles.*
April	26.3	2.5	12.4
May	26.1	3.2	12.7
June	24.6	2.6	10.8
July	23.6	2.2	9.7
August	24.7	2.4	10.8

The tanks were filled September 1. Moisture determinations made from the soil samples taken as the tanks were filled showed a very high percentage of moisture, and for that reason a 4.5-inch—68 pounds—instead of a 6-inch irrigation was applied. The mulches were applied as soon as the water had disappeared from the soil surface.

Following is a summary of these moisture determinations made at the beginning and end of the experiment:

Moisture determinations at beginning and end of the experiment.

	Beginning.	End.
	Per cent.	*Per cent.*
Tanks 1 and 2	23.21	26.48
Tanks 3 and 4	22.94	26.50
Tanks 5 and 6	21.68	26.92
Tanks 7 and 8	21.31	28.12

The percentage of moisture in dry mulch was 2.3 per cent of its dry weight.

The climatological data and the losses from the several tanks by three and four day periods are given in the following tables:

Mean maximum atmospheric, soil, and water temperatures, and the rainfall at Bozeman, Mont., Sept. 2 to 30, 1908.

Periods.	Mean maximum temperature.	Mean maximum soil temperature.[1]	Mean maximum water temperature.[1]	Rainfall.
	°F.	*°F.*	*°F.*	*Inches.*
Sept. 2-5	65.6	77.5	71.0	
Sept. 5-9	86.8	79.5	73.5	
Sept. 9-12	79.3	78.0	67.0	
Sept. 12-16	82.5	73.7	66.7	0.08
Sept. 16-19	60.2	64.3	62.0	.35
Sept. 19-23	72.1	73.3	64.7	
Sept. 23-26	60.8	62.0	55.5	.69
Sept. 26-30	61.1	56.5	55.5	
Average, 28 days	71.8	70.6	64.4	

[1] Taken at depth of 3 inches.

Evaporation from a free-water surface and from soils protected by different depths of mulches at Bozeman, Mont., Sept. 2 to 30, 1908.[1]

Periods.	Loss from water surface.	Loss from soil.							
		No mulch, tanks 1 and 2.		3-inch mulch, tanks 3 and 4.		6-inch mulch, tanks 5 and 6.		9-inch mulch, tanks 7 and 8.	
Average weight of tanks Sept. 2, pounds		1,282.7		1,282		1,286		1,292.2	
Average loss:	*Inches.*	*Pounds.*	*P. ct.*	*Pounds.*	*P. ct.*	*Pounds.*	*P. ct.*	*Pounds.*	*P. ct.*
Sept. 2-5	0.54	8.87	9.3	0.50	0.5	[2] −0.87	−0.9	1.00	1.1
Sept. 5-9	.88	10.37	11.0	5.00	5.3	[2] −2.50	−2.7	.25	.3
Sept. 9-12	.56	6.00	6.4	3.25	3.5	1.25	1.3	.12	.1
Sept. 12-16	.93	7.00	7.4	5.75	6.2	3.00	3.2	1.12	1.2
Sept. 16-19	.75	4.73	5.0	4.60	4.9	3.23	3.4	2.35	2.5
Sept. 19-23	.87	8.00	8.5	6.12	6.5	5.25	5.6	4.12	4.4
Sept. 23-26	[3] +.72	[3] −3.19	−3.4	[3] −3.56	−3.8	[3] −3.19	−3.4	[3] −3.81	−4.1
Sept. 26-30	.30	4.50	5.3	3.12	3.3	4.37	4.6	5.62	6.0
Total loss, 28 days	4.11	46.28	49.5	24.78	26.4	10.46	11.1	10.77	11.5
Equivalent losses in inches		2.95		1.58		.66		.69	

[1] Per cent calculated on basis of 6-inch irrigation, owing to high percentage of soil moisture.
[2] Due to inaccuracies in weighing.
[3] Due to rainfall.

The most noticeable feature of the results at this station was the very heavy evaporation losses, especially from the unmulched soils. During the first week 1.23 inches, or 20.5 per cent of the total amount of water added in the irrigation to the unmulched surfaces, was lost by evaporation, and by the end of four weeks a total of 46.28 pounds, or 49.5 per cent of the amount applied, had been lost.[1] Heavy losses were also found with the different mulches, the 3-inch mulch losing 1.58 inches, or 26.3 per cent of the water added in irrigation, in 28 days, showing a saving of 46 per cent of the water lost from an unmulched surface. The 9-inch mulch showed a saving of approximately 77 per cent of the loss from the unmulched surface and 57 per cent of the amount lost through the 3-inch mulch. Until rainfall interfered a much greater advantage was being shown in favor of the 9-inch mulch, but after the first two weeks the effect of all the mulches was more or less destroyed by the rainfall, and toward the end of the month heavy losses were recorded from all of the tanks. Although the losses with the 6-inch mulches are included in the table, they have little value, owing to inaccuracies in weight at the end of the first and second periods.

---

[1] Owing to the high percentage of soil moisture the amount applied is considered as 6 inches rather than 4½ inches.

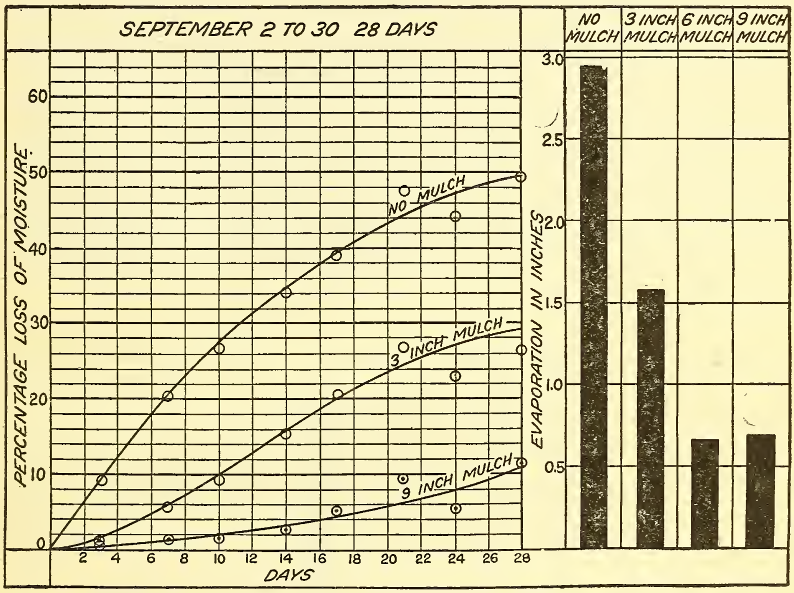

FIG. 6.—Evaporation losses from tanks of soil protected by mulches of different depths at Bozeman, Mont., September 2-30, 1908.

It may be well to call attention to the effect of the percentage of moisture in the soil upon the rate of evaporation. The exceedingly heavy losses from the soil under ordinary climatic conditions, which produced only moderate losses from a free-water surface, can be accounted for only by the wet condition of the soil, analyses of which showed the average free-moisture content to be 22.3 per cent.

Figure 6 shows the total losses from the several tanks[1] in inches, and the percentage of the water applied lost during each three and four day period.

---

[1] Curve for 6-inch mulch omitted, owing to inaccuracies in weights.

RESULTS AT WENATCHEE, WASH.

The experiments in the State of Washington were made in the Wenatchee fruit district of Chelan County, in an orchard about 1½ miles west of the town of Wenatchee. The spot chosen for the experiment is typical of a large area as to climatic and soil conditions, since the bars and benches farther up the Columbia River and thousands of acres along the tributary streams, even as far north as British Columbia, are similar to those of the Wenatchee district. The soil in the orchard chosen was a sandy loam inclined to be gritty, several feet in depth, and fairly typical of that generally found in the locality. Scarcely a perceptible difference was found in the nature of the soil in the first 4 feet in depth. The subsoil as far as was ascertained consisted of gravelly bowlders or loose rock, affording perfect drainage. (Pl. II,[1] fig. 1.)

Records of the United States Weather Bureau station located in the foothills near Wenatchee, at an elevation of 1,150 feet, give a mean annual temperature of 47.9° and a normal precipitation of 15.54 inches, 4.74 inches of which falls between April 1 and October 1. The temperature of Wenatchee is somewhat higher than this, and the precipitation is probably 3 or 4 inches less than the above.

The experiment was started June 3 and continued until June 24, and was repeated September 8 to September 29, a 6-inch irrigation being applied in each case.

The first trial was made June 3 to 24, 1908.

Soil samples were taken as the tanks were being filled, and moisture determinations made later. Another set of determinations was made at the end of the experiment, the results of these determinations being given in the following table:

Soil-moisture determinations at beginning and end of the experiment.

	Mean moisture content before irrigation.	Moisture content at end of experiment.			
		First foot.	Second foot.	Third foot.	Mean.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Tank No. 1	6.0	6.5	8.0	15.5	10.0
Tank No. 2	13.0	16.0	16.0	17.0	16.3
Tank No. 3	8.0	8.0	8.5	16.5	11.0
Tank No. 4	6.5	8.0	9.0	15.0	10.7
Tank No. 5	2.0	6.0	7.0	15.5	9.5
Tank No. 6	7.0	7.0	9.0	18.5	11.5
Tank No. 7	11.0	14.0	16.5	19.0	16.5
Tank No. 8	7.5	9.0	11.0	18.0	12.7

During the progress of the experiment the weather was warm, with a considerable amount of wind. The rainfall during the period was not enough to interfere with the experiment.

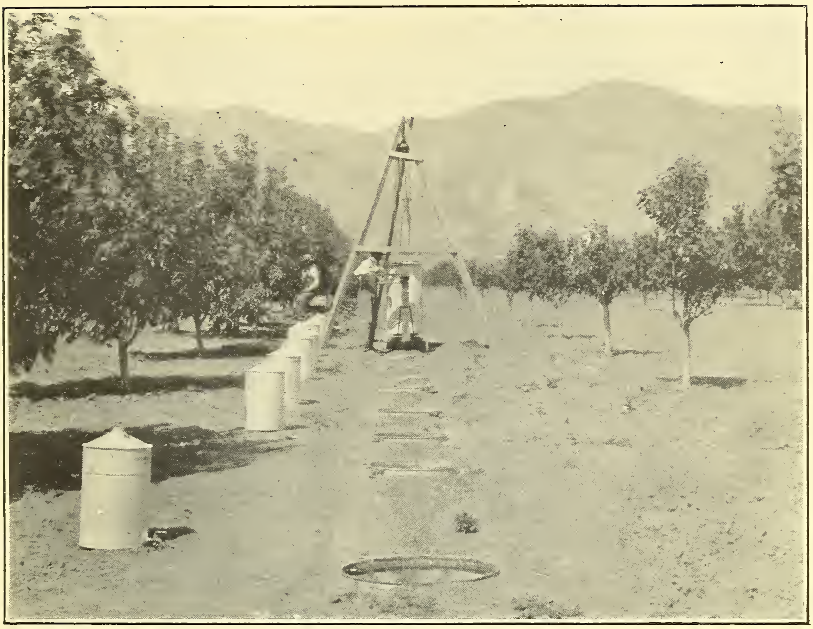

FIG. 1.—EXPERIMENT TRACT, WENATCHEE, WASH.

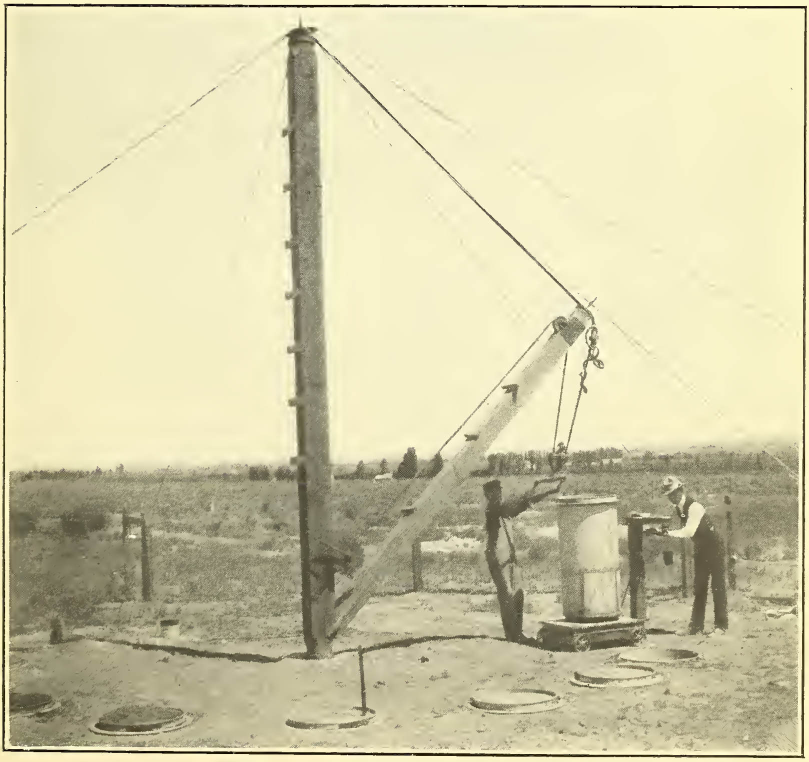

FIG. 2.—EXPERIMENT TRACT, CALDWELL, IDAHO.

The following table shows the maximum temperature of the air, evaporation losses from a free-water surface, and the losses from the several tanks:

Mean maximum temperature and evaporation from free-water surface, and soils protected by mulches of different depths, Wenatchee, Wash., June 3–24, 1908.

Periods.	Mean maximum temperature.	Loss from water surface.	Loss from soil							
			No mulch, tank 1.		3-inch mulch, tanks 3 and 4.		6-inch mulch, tanks 5 and 6.		9-inch mulch, tank 8.	
Average weight of tanks June 3, pounds	....	....	1,365		1,324.7		1,362.5		1,379.5	
Average loss:	°*F.*	*Inches.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
June 3–6	76.0	....	9.0	9.5	1.75	1.9	1.25	1.3	0.50	0.5
June 6–10	85.0	2.00	2.5	2.7	1.00	1.1	.25	.3	.25	.3
June 10–13	83.3	....	1.5	1.6	.50	.5	.25	.3	.25	.3
June 13–17	83.3	2.25	....	....	.50	.5	....	....	....	....
June 17–20	70.6	....	.5	.5	....	....	....	....	....	....
June 20–24	74.2	1.87	....	....	....	....	.25	.3	....	....
Total loss	[1] 79.0	6.12	13.5	14.4	3.75	4.0	2.00	2.2	1.00	1.1
Equivalent loss in inches	....	....	.86		.24		.13		.07	

[1] Average, 21 days.

The most noticeable feature of the results of this experiment was the small losses shown throughout, notwithstanding that moderate temperatures prevailed and that a rather heavy evaporation was recorded from the water surface. The losses after the first three days were practically negligible. This may be accounted for in two ways; first, the low percentage of moisture in the soil before irrigation, and, second, the general texture of the soil, which allowed most of the water to collect in the lower layer, as is shown by the high percentage of moisture in the third foot at the end of the experiment. The unmulched surface lost an equivalent of 0.86 inch of water, which is but 14.3 per cent of the total amount applied and 66 per cent of this was lost in the first three days. The 3-inch mulch showed a loss of 0.24 inch, or a saving of 72 per cent of the loss from the unmulched surface. As usual, there is very little difference between the 6 and the 9 inch mulches, the former showing a loss of 0.13 inch and the latter 0.07 inch, being savings of 85 and 92.5 per cent, respectively, of the loss from the bare surface.

The losses from tanks 2 and 7 have been omitted in these results. Tank 2 showed a total loss of 52 pounds and tank 7 a loss of 10.5 pounds for the period. These losses can be accounted for only by the heavy percentage of moisture in the soil before irrigation. The moisture in tank 7 arose through the 9-inch mulch almost as soon as it was applied, completely destroying its value as a mulch. This shows beyond doubt that the controlling element in evaporation losses is the percentage of moisture in the soil.

Figure 7 illustrates the difference in evaporation losses between the four sets of tanks.

In the second trial, September 8–29, 1908, the auxiliary data such as moisture percentages, temperatures, evaporation from free-water surface, etc., are entirely missing, so that the results as in the following table possess little comparative value:

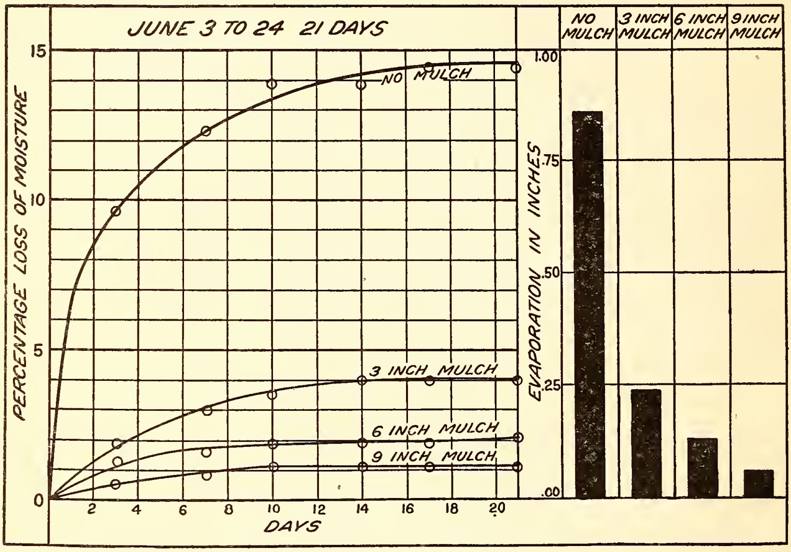

Fig. 7.—Evaporation losses from tanks of soil protected by mulches of different depths at Wenatchee, Wash., June 3-24, 1908.

Results of experiment Sept. 8–29, 1908.

Kind of mulch.	Loss in 21 days.		Percentage lost of 6-inch irrigation.	Percentage of saving due to mulch.
	Pounds.	*Inches.*		
None	13.50	0.86	14.33	....
3-inch	12.75	.81	13.56	4.8
6-inch	8.75	.56	9.29	30.0
9-inch	7.75	.49	8.23	36.5

SUMMARY OF RESULTS.

The table following shows the averages of the losses recorded at the five stations.

Average losses by evaporation from free-water surface and from tanks with mulches of different depths at the five stations.[1]

Periods.	Days.	Loss from water surface.[2]	Loss from soil.			
			No mulch.	3-inch mulch.	6-inch mulch.[3]	9-inch mulch.
		Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First	3	0.86	9.6	1.9	0.48	0.48
Second	4	.95	5.1	2.1	.56	.56
Third	3	.87	3.7	1.6	.63	.25
Fourth	4	.95	3.6	2.3	.89	.43
Fifth	3	.97	2.3	1.5	1.08	.53
Sixth	4	.99	3.1	2.4	1.73	1.07
Total	21	5.59	27.4	11.8	5.37	3.32
Equivalent loss in inches			1.75	.75	.34	.22

[1] In compiling this table the losses used for Agricultural College, N. Mex., and Davis, Cal., are averages of the two experiments at each place.

[2] Losses at Reno, Nev., assumed to be uniform throughout each week.

[3] Owing to inaccuracies in weighing tanks at Bozeman, losses for first seven days assumed to be same as from tanks with 9-inch mulch.

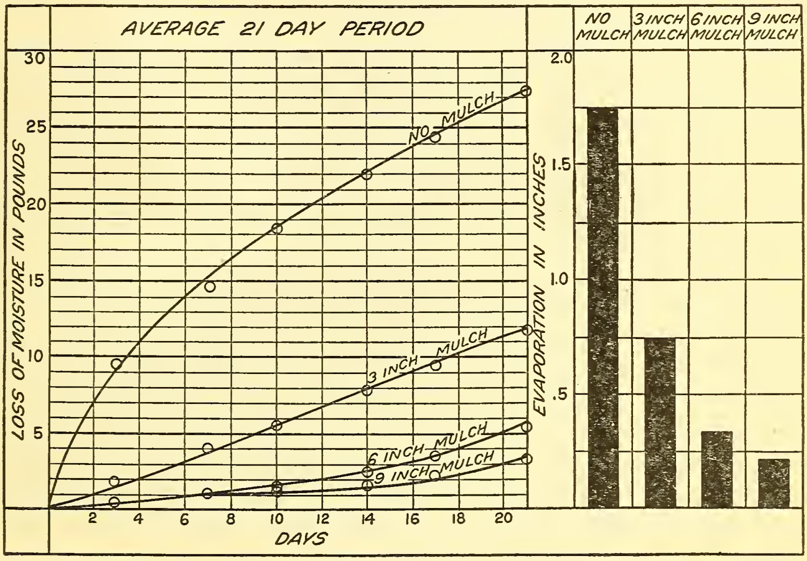

FIG. 8.—Average evaporation losses from tanks of soil protected with mulches of different depths during first 21 days after irrigation. Average of losses at five stations.

Figure 8 is a graphic representation of the foregoing table, showing a summary and comparison of these losses and the evaporation losses by three and four day periods at all of the five stations.

The most noticeable feature of these results is the uniformity of the losses. This is remarkable when it is remembered that they represent an average of the losses at all of the five stations.

The average loss from an open unmulched soil surface for a period of three weeks was 27.4 pounds, which is equivalent to 1.75 inches of water. The average loss during the first three days after irrigation amounted to 0.61 inch, almost as much as the average loss from a free-water surface. The loss during the first week was over 54 per cent of the total loss for 21 days. After the first week the losses diminished very gradually until during the last four-day period the loss was equivalent to only 0.20 inch of water.

After the first three days the daily loss from a 3-inch mulch was almost constant, a straight line curve passing very close to all of the points, as shown by the curve diagram. The total loss for the three weeks amounted to 0.75 inch, and shows a saving of 57 per cent of the water lost from an unmulched surface. When the dry mulch was applied to the irrigated soil surface, the moisture, due to capillarity, immediately started upward through the mulch, and as this moisture reached the surface, varying losses are recorded for the first few days; after this the mulch seems to adjust itself and constant losses are recorded for the remaining 18 days. At all times the surface of the mulch appeared perfectly dry, moisture not being found at a depth of less than 0.5 inch.

The losses with the 6 and 9 inch mulches were quite small. That with the 6-inch mulch was only 0.34 inch, or 5.7 per cent of the 6-inch irrigation, and a saving of 54.7 per cent of the loss with the 3-inch mulch. The loss with the 9-inch mulch was only 0.22 inch, or 3.7 per cent of the water applied, and only a very little more than one-third of the loss from the unmulched tanks during the first three days after irrigation.

As has been stated, one of the chief objections to many of the experiments which have been carried on by various investigators in the past, is that the results obtained are of only local value and do not cover territory enough to give reliable data for the varying conditions of widely separated localities. The five localities in which this experiment was carried on are far apart, typical of the country surrounding them, and vary greatly in soil conditions, temperatures, wind movement, etc., and the average results given here may be used anywhere in the arid West without serious variation.

In the table following the results from all of the stations have been assembled, temperatures, rainfall, and evaporation from soil and water surfaces being shown.

Results of five stations grouped: Showing temperature, rainfall, and evaporation losses from soils (in tanks) under mulches of varying depths. Period covered 21 days and a 6-inch irrigation the basis of the test.

Locations.	Mean temperature.	Rainfall.	Loss from water surface.	Percentage of soil moisture before irrigation.	Losses by evaporation.							
					No mulch.		3-inch mulch.		6-inch mulch.		9-inch mulch.	
	°F.	*Ins.*	*Ins.*	*P. ct.*	*Ins.*	*P. ct.*	*Ins.*	*P. ct.*	*Ins.*	*P. ct.*	*Ins.*	*P. ct.*
Agricultural College, N. Mex	44.8	0.56	4.50	......	1.99	......	0.60	......	0.23	......	0.23	......
Bozeman, Mont	52.8	.43	4.53	22.3	2.86	47.6	1.61	26.9	......	......	.57	9.6
Davis, Cal	71.2	......	8.02	8.8	1.62	27.0	.48	8.0	.14	2.3	.01	.2
Reno, Nev	......	.30	4.68	7.2	1.41	23.6	.88	14.6	.36	6.0	.17	2.9
Wenatchee, Wash	62.3	......	6.12	6.2	.86	14.4	.24	4.0	.13	2.2	.07	1.2

This table shows that although the stations having highest mean temperatures produced the greatest evaporation from a free-water surface it was not at these that the greatest evaporation losses from the soil occurred. The stations having the lowest mean temperatures and the least evaporation from a free-water surface gauge the highest losses from soils. This indicates quite clearly that climatic conditions are not the controlling factor in evaporation from soils. California, with the highest mean atmospheric temperature and the greatest evaporation loss from a water surface, shows slightly over one-half of the evaporation loss from an unmulched soil surface as does Montana with an average temperature which is 20° lower and an evaporation loss from a water surface of 3.48 inches less for the three-weeks period. At all but the New Mexico station moisture determinations of the soil were made before irrigation and in each case inspection of the results shows that the losses from the soil vary with the percentage of moisture in the top layer. The influence of both temperature and wind movement in causing the evaporation losses from soils appears to be much less than that of the moisture content in the top layer.

CONCLUSIONS.

(1) Soil mulches subserve many useful purposes, chief of which is the lessening of evaporation losses from the surface of cultivated soils.

(2) When western soil containing sufficient moisture to germinate seed and maintain plant growth is irrigated to a depth of 6 inches over the surface (one-half acre-foot per acre) and not cultivated afterwards, it is safe to assume that 1½ to 2 inches of the 6 inches applied will be lost by evaporation in a period of 30 days.

(3) The quantity lost by evaporation will increase with the percentage of moisture in the soil. In extreme cases of heavy moisture

content and high temperatures, 3 to 4 inches may be lost in a 30-day period.

(4) A dry, granular soil mulch 3 inches deep, such as was used in these experiments, will save, other conditions being similar, at least one-half of the loss from an unmulched surface.

(5) A like mulch 6 inches deep will save 75 per cent of the evaporation losses from an unmulched surface.

(6) In comparing the efficiency of a 6-inch mulch with a 9-inch mulch, the results show a considerable saving of water by the deeper mulch but the cost of cultivation and other practical considerations would seem to limit the depth to 6 inches or less. This applies to the greater part of the arid region.

(7) It is also well to remember that the mulches used in these experiments were ideal as regards their efficiency in checking evaporation, and in very few cases could they be produced in actual field cultivation, but obviously the nearer they are approached, the greater is the saving, and this alone should be an incentive to deeper and more thorough cultivation after irrigation.

EFFECTS OF CULTIVATION TO DIFFERENT DEPTHS.

In the foregoing series of experiments, as stated, the mulch was artificially prepared and superimposed on the tanks of irrigated soil. This method permitted of greater precision in preparing and measuring the depth of mulches; yet in some minor respects differed from field conditions. In the present series the process of natural cultivation was more nearly followed. All tanks were filled to within 1 inch of the top with fresh soil, the same care of arrangement being exercised as in the former series. At a suitable time after irrigation the top soil was mulched by spading and thoroughly cultivating to different depths. Different periods of time were also allowed to elapse between irrigation and cultivation and corresponding effects on evaporation losses noted.

It is generally known among irrigators that there is a saving of moisture and a general improvement in the condition of the soil if cultivation is practiced after irrigation, but too often this knowledge is not put into practice. This is especially true in localities where water is plentiful, it being considered easier to apply another irrigation after the surface soil has dried out than to prevent loss of moisture by cultivation. In general the practice of cultivation seems to depend upon the scarcity and value of water, and where water is scarce and water rentals are high cultivation is quite generally practiced and every effort made to conserve the moisture in the soil.

The main purpose of the experiment outlined below was to determine, first, the losses by evaporation from cultivated and uncultivated soil surfaces after irrigation; second, the percentage of water saved by cultivation after irrigation; and, third, the amount of water lost in the period between the time of irrigation and cultivation. In addition to the five stations described in the former experiment, apparatus was installed at Caldwell, Idaho, and Williston, N. Dak. In all cases soil containing excessive moisture was avoided, and as the tanks were filled, samples were taken and moisture determinations made. Each tank was then given a 6-inch irrigation, the water being added from 5 or 10 gallon cans and the flow regulated so as to keep the entire surface flooded with at least 0.5 inch of water until the whole had been applied. Immediately after irrigation all of the tanks were weighed, and as soon as the soil was sufficiently dry four of them were cultivated to a depth of 6 inches, an attempt having been made to do this in such a way as to approach as nearly as possible ordinary cultural methods. The soil surfaces of the remaining four tanks were not disturbed during the test.

In each case the period between irrigation and cultivation was noted. This varied with the percentage of moisture in the soil, the the general texture of the soil, and the climatic conditions. At the end of two weeks cultivation was again practiced in the cultivated tanks and weighings continued for another two weeks. At the end of four weeks the tanks were emptied, the general condition of the soil observed, and samples taken for moisture determinations. The tanks were again filled, and the experiments repeated during the following month.

RESULTS AT SUNNYSIDE, WASH.

The equipment used the previous season at Wenatchee was transferred to the experiment station near Sunnyside, where the experiment was made. The soil used in these tests is typical of the Yakima Valley, being a sandy loam with no change or intervening strata in the upper 4 feet. This uniform fineness of the soil was found to aid materially in its water-holding capacity.

The tanks were filled on May 17, and a 6-inch irrigation given the following day. Analysis of soil samples taken at the time of filling gave an average of 6 per cent of free moisture and a period of seven hours was noted between the beginning of the irrigation and the time when the water had finally disappeared from the surface of the soil. This short period shows the capacity of the soil for absorbing water. Two days after irrigation tanks 1, 2, 3, and 4 were cultivated to a depth of 6 inches, and after a period of two weeks they were given another cultivation.

The accompanying tables show the climatological data and the losses from the several tanks for three and four day periods. The graphical diagram (fig. 9) shows the daily average rate of loss from cultivated and uncultivated surfaces in percentage of the 6-inch irrigation and a comparison of the losses figured in inches of water:

Temperatures of air, water, and soil at Sunnyside, Wash. (May 18 to June 15, 1909).

Periods.	Days.	Mean atmospheric temperature.	Mean soil temperature uncultivated.[1]	Mean soil temperature cultivated.[1]	Mean water temperature.
		°*F.*	°*F.*	°*F.*	°*F.*
First	3	61.0	64.4	63.5	67.1
Second	4	62.0	68.7	68.4	70.0
Third	3	65.3	72.2	70.1	67.4
Fourth	4	66.7	73.7	69.5	67.7
Fifth	3	71.1	79.7	75.2	75.2
Sixth	4	63.7	77.5	72.0	71.3
Seventh	3	66.6	77.9	74.3	74.9
Eighth	4	65.9	77.4	76.4	73.9
Average	28	65.2	74.3	71.3	70.9

[1] Taken at depth of 3 inches.

Evaporation losses from cultivated and uncultivated tanks at Sunnyside, Wash.[1] *(May 18 to June 15, 1909).*

Periods.	Days.	Cultivated.				Uncultivated.			
		Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
Average weight of tank May 18, pounds	....	1,196.0		1,183.5		1,200.5		1,196.0	
		Pounds.	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*
First	3	14.00	14.9	12.50	13.3	10.50	11.2	10.00	10.6
Second	4	3.00	3.2	3.00	3.2	10.25	10.9	10.50	11.2
Third	3	2.00	2.1	2.50	2.6	6.75	7.2	5.00	5.3
Fourth	4	.75	.8	....	....	2.00	2.1	4.00	4.2
Fifth	3	3.50	3.7	4.50	4.8	3.50	3.7	3.00	3.2
Sixth	4	[2]−2.25	−2.4	[2]−1.25	−1.3	1.75	1.9	1.00	1.1
Seventh	3	1.50	1.6	.25	.3	2.00	2.1	1.25	1.3
Eighth	4	1.00	1.1	1.25	1.3	2.75	2.9	3.25	3.5
Total loss	28	23.50	25.0	22.75	24.2	39.50	42.0	38.00	40.4
Equivalent loss in inches	....	....	1.47		....	....	2.47		....

[1] Total evaporation from free-water surface for 28 days, 7.25 inches.
[2] Probably due to inaccuracy in weighing.

It is well to remember that in this experiment the initial percentage of moisture in the soil was low, and that only a period of two days intervened between irrigation and cultivation. The losses shown for the first three days are higher from the cultivated than from the uncultivated tanks. This is due to the fresh moist soil being exposed in cultivation. After this first loss the losses from the cultivated tanks diminished rapidly until the second cultivation two weeks later, when the losses for one period were again quite heavy. During the remainder of the experiment the losses were very small, and in one case a gain was shown. This gain may have been due to some error in the weighing apparatus. The average total loss for 28 days from the cultivated tanks was 1.47 inches, or 24.5 per cent of the 6-inch irrigation. The loss in the period between irrigation and cultivation was probably approximately 10 pounds, or slightly less than 50 per cent of the total loss.

The average total loss from the uncultivated surface amounted to an equivalent of 2.47 inches, which is 41.2 per cent of the 6-inch irrigation. Fifty-three per cent of the loss occurred in the first week after irrigation. After the first week the losses were quite uniform, a small increase being noticed in the fifth period, which undoubtedly was due to the high mean temperatures at that time.

Although this experiment showed that the average evaporation from the cultivated surfaces was a little less than 60 per cent of that from the uncultivated surfaces, the main feature brought out was the necessity of cultivation as soon after irrigation as possible.

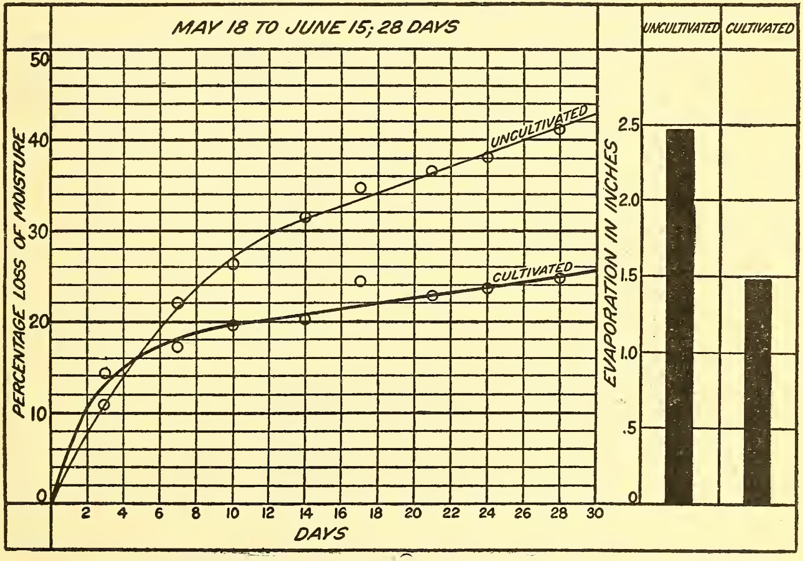

FIG. 9.—Evaporation losses from cultivated and uncultivated tanks at Sunnyside, Wash., May 18 to June 15, 1909.

The soil temperatures taken at a depth of 3 inches follow very closely the changes in the atmospheric temperatures, but there is an average difference of almost 2° in the temperatures of the cultivated and uncultivated soils, the cultivated soil being cooler to that extent.

RESULTS AT DAVIS, CAL.

This experiment extended over two periods—May 5 to June 2 and June 5 to July 3. The same site was chosen and the same equipment used as in the soil-mulch experiments of the season of 1908. The usual care was taken in filling the tanks to produce as nearly as possible natural field conditions, soil samples being taken which gave the following average percentages of free moisture: May 5, 9.8 per cent;

June 5, 15.9 per cent. The higher percentage of free moisture and the higher temperature increased the losses in the second period, although close observations of the results show that the ratios of the losses from the cultivated and uncultivated surfaces were practically the same. In each case the time of the beginning of irrigation and the time at which the water disappeared from the soil surface were recorded. The weight of the soil, the time required for the water to seep away, and the percentages of free moisture for each tank recorded for each period are given below:

Weight of tanks, length of irrigation, time before cultivation, and percentage of free moisture in tanks.

FIRST PERIOD, MAY 5 TO JUNE 2, 1909.

Tanks.	Weight of soil before irrigation.	Time required for irrigation.	Time between irrigation and cultivation.	Percentage of free moisture before irrigation.
	Pounds.	*Hours.*	*Hours.*	*Per cent.*
No. 1	1,086.5	$6\frac{7}{12}$	42	11.46
No. 2	1,108.0	$6\frac{1}{3}$	42	10.96
No. 3	1,089.5	$6\frac{3}{4}$	42	10.81
No. 4	1,075.5	6	42	9.64
No. 5	1,095.0	$6\frac{1}{4}$	42	9.58
No. 6	1,101.5	6	42	8.56
No. 7	1,098.0	6	42	10.04
No. 8	1,093.0	$6\frac{5}{12}$	42	7.64

SECOND PERIOD, JUNE 5 TO JULY 3, 1909.

Tanks.	Weight of soil before irrigation.	Time required for irrigation.	Time between irrigation and cultivation.	Percentage of free moisture before irrigation.
No. 1	1,173.0	$6\frac{1}{4}$	64	14.54
No. 2	1,149.5	$5\frac{3}{4}$	64	14.54
No. 3	1,153.5	6	64	17.55
No. 4	1,147.0	$5\frac{3}{4}$	64	17.55
No. 5	1,149.0	$5\frac{3}{4}$	64	15.45
No. 6	1,150.0	$6\frac{1}{6}$	64	15.45
No. 7	1,137.5	$5\frac{5}{6}$	64	16.10
No. 8	1,148.0	6	64	16.10

Immediately after irrigation the tanks were weighed and for the next four weeks weights were taken twice a week at the end of each 3 and 4 day period. Tanks 1, 2, 3, and 4 were cultivated a second time to a depth of 6 inches at the end of the first two weeks. At the time of this second cultivation moisture was found at a depth of $1\frac{1}{2}$ inches. Above this depth the soil was dry and acted as a mulch, while at the end of each test soil samples were taken for moisture determinations. These showed that in every case the 6-inch irrigation had penetrated the full depth of the soil, although there was no free water or even an excess of moisture in the bottom layers.

During the next two months quite complete climatological observations were made. These are included in the table following.

Temperature of air, soil, and water, mean humidity, and wind velocity at Davis, Cal. (May 5 to June 2 and June 5 to July 3, 1909).

Periods.	Days.	Mean atmospheric temperature.	Mean soil temperature.[1]	Mean water temperature.[1]	Mean humdity.	Mean wind velocity per hour.
		°*F.*	°*F.*	°*F.*	*Per cent.*	*Miles.*
First	3	67.2	74.8	74.9	54.0	8.38
Second	4	63.7	75.2	72.6	48.0	8.64
Third	3	61.8	74.5	71.5	47.7	11.90
Fourth	4	59.6	72.6	69.3	64.6	9.10
Fifth	3	62.8	74.6	73.5	54.0	8.60
Sixth	4	67.5	77.4	74.7	40.1	10.15
Seventh	3	60.8	77.9	72.8	45.4	10.65
Eighth	4	71.2	78.7	76.6	44.6	7.60
Average	28	64.5	75.7	73.2	49.8	9.32

[1] Taken at a depth of 6 inches.

The losses from the several tanks between the different irrigations are shown in the following table:

Average evaporation losses from free-water surface and from cultivated and uncultivated surfaces at Davis, Cal. (May 5 to June 2 and June 5 to July 3, 1909).

Periods.	Days.	Mean loss from water surface.	Cultivated.				Uncultivated.			
			Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
Average weight of tanks at beginning of experiment, pounds	....	....	1,133		1,116		1,124		1,119	
		Inches.	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*
First	3	1.05	10.25	10.9	10.10	10.7	11.50	12.2	11.40	12.1
Second	4	1.22	5.00	5.3	3.40	3.6	6.25	6.7	5.75	6.1
Third	3	1.24	1.25	1.3	1.00	1.1	2.75	3.0	3.10	3.3
Fourth	4	.99	1.00	1.1	.75	.8	2.00	2.1	2.40	2.6
Fifth	3	1.16	4.25	4.5	3.00	3.2	1.85	2.0	2.25	2.4
Sixth	4	1.36	.75	.8	.75	.8	2.35	2.5	2.50	2.7
Seventh	3	1.22	.60	.6	.50	.5	1.75	1.9	1.25	1.3
Eighth	4	1.17	.15	.2	.15	.2	1.75	1.9	1.10	1.2
Total	28	9.41	23.25	24.7	19.65	20.9	30.2	32.3	29.75	31.7
Equivalent of average loss of water in inches	....	....	....	1.36		....	....	1.91		....

A comparison of the quantities of water lost from cultivated and uncultivated soils, and the variation of these losses in percentages of the 6-inch irrigation, are shown in figure 10.

The table following shows the variations between the losses during the two periods considered independently of each other.

Variation in temperature, evaporation loss, and percentage of free moisture in two experiments at Davis, Cal.

Periods.	Mean temperature.	Mean soil temperature.	Mean water temperature.	Wind velocity per hour.	Evaporation loss from water surface.	Loss from uncultivated soil.	Loss from cultivated soil.	Loss saved by cultivation.	Free moisture.
	°*F.*	°*F.*	°*F.*	*Miles.*	*Inches.*	*Pounds.*	*Pounds.*	*Per ct.*	*Per ct.*
First—May 5 to June 2	60.1	71.6	70.0	9.00	8.39	26.29	17.6	32.8	9.8
Second—June 5 to July 3	68.6	80.0	76.1	9.75	10.46	33.50	25.6	23.6	15.9

The heavy losses from June 5 to July 3 as compared with those from May 5 to June 2 are very noticeable both from the cultivated and the uncultivated soils. Although the average temperatures are considerably higher from June 5 to July 3, the differences were not great enough to account for the large variations in the evaporation from the soil surfaces, as the ratios existing between the losses from the soil were considerably greater than those existing between the losses from the water surfaces. The cause of the greater losses in the last trial was the excess of moisture in the soil at the beginning of the experiment.

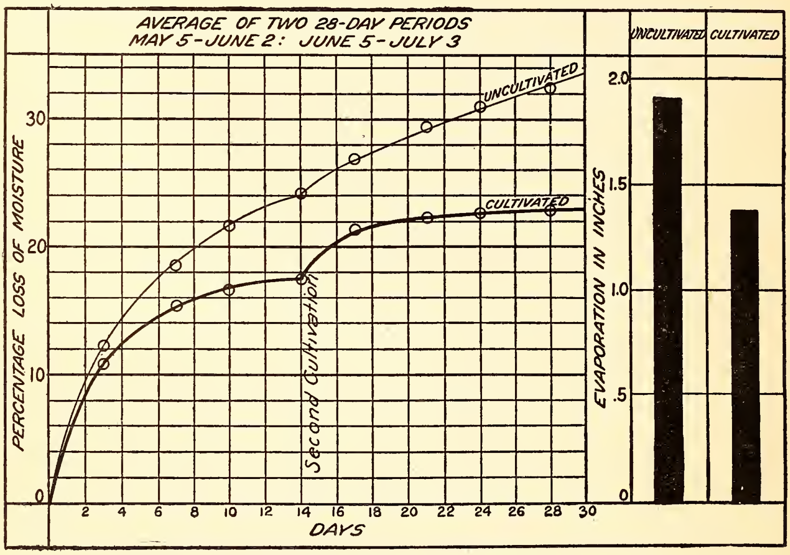

FIG. 10.—Average evaporation losses from cultivated and uncultivated tanks at Davis, Cal., May 5 to June 2 and June 5 to July 3, 1909.

From the results of the combined table for the two experiments, the uncultivated soil surfaces show a loss of 1.91 inches, which is 32 per cent of the 6 inches applied in the irrigation. Thirty-eight per cent of this was lost in the first three days. The cultivated surfaces show an equivalent loss of 1.36 inches, a saving of 28.2 per cent of the loss from the uncultivated surfaces. At least 40 per cent of the total loss from cultivated surfaces occurred in the period between irrigation and cultivation.

The cultivated surfaces showed an increased loss during the period of the second cultivation, but this loss lasted for only one three-day period, after which the losses became smaller than ever and continued to decrease until the end of the experiment. The losses from the uncultivated surfaces showed a very uniform decrease after the first week, but at the end of three weeks they were still quite heavy.

RESULTS AT RENO, NEV.

The site for those experiments was changed from that of the season of 1908 to the central portion of the Nevada Experiment Station. The new plat had been used previously for dry-farm crops, but the soil conditions were the same as those of the soil-mulch experiment of the previous season. The experiment was begun May 7 and extended through two periods—May 7 to June 4 and June 8 to July 6. The tanks were installed, filled, and irrigated after the methods described for the other stations.

Soil samples taken at the time of filling gave the following percentages of free moisture and show a very even distribution of moisture through the soil:

Percentage of free moisture in each foot of soil at beginning of the experiments.

Depth.	May 7.	June 8.
	Per cent.	*Per cent.*
1 foot	8.35	7.80
2 feet	8.35	9.40
3 feet	8.80	9.70
4 feet	9.20	9.40
Mean	8.68	9.08

The light texture of the soil, the low percentage of moisture before irrigation, and the warm weather made cultivation possible in each case within 24 to 30 hours after irrigation. Two weeks later a second cultivation was given.

Climatological data and the average losses from the several tanks are given in the following tables:

Average temperature of air and soil, humidity, wind velocity, and rainfall at Reno, Nev. (May 7 to June 4 and June 8 to July 6, 1909).

Periods.	Days.	Mean temperature.	Mean soil temperature.	Mean humidity.	Mean wind velocity per hour.	Rainfall.
		°F.	*°F.*	*Per cent.*	*Miles.*	*Inch.*
First	3	52.2	64.8	52.3	6.15	....
Second	4	51.2	68.3	51.1	5.40	0.02
Third	3	53.5	62.6	56.9	7.50	.26
Fourth	4	53.9	63.5	65.1	5.30	.01
Fifth	4	56.8	68.0	50.2	5.80	.08
Sixth	4	59.3	70.6	68.4	8.10	....
Seventh	3	59.5	68.2	52.9	6.10	.02
Eighth	4	65.6	75.5	68.4	6.80	....
Average	28	56.6	67.9	58.9	6.40	....

Average evaporation losses from free-water surface and from cultivated and uncultivated surfaces at Reno, Nev. (May 7 to June 4 and June 8 to July 6, 1909).

Periods.	Days.	Loss from water surface.	Cultivated.				Uncultivated.			
			Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
Average weight of tanks at beginning of experiment, pounds	....	....	1,247		1,227		1,272		1,253	
Average loss:		*Inches.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
First	3	1.12	8.90	9.5	9.00	9.6	11.90	12.6	11.75	12.5
Second	4	1.12	2.40	2.6	2.60	2.8	1.90	2.0	3.50	3.7
Third	3	.94	.45	.5	.75	.8	1.30	1.4	1.25	1.3
Fourth	4	.61	1.40	1.5	.70	.7	2.60	2.8	2.30	2.5
Fifth	3	.76	1.20	1.3	1.00	1.1	2.00	2.1	1.85	2.0
Sixth	4	1.07	1.25	1.3	1.50	1.6	1.10	1.2	1.35	1.4
Seventh	3	1.36	1.00	1.1	1.00	1.1	1.00	1.1	1.40	1.5
Eighth	4	1.51	.50	.5	.50	.5	1.00	1.1	1.30	1.4
Average total loss	28	8.49	17.10	18.3	17.05	18.2	22.80	24.3	24.70	26.3
Equivalent of average loss in inches	....	....	....	1.09		....	....	1.51		....

The losses are also shown graphically in figure 11.

These results show very small average losses from both cultivated and uncultivated soils, but when it is considered that this soil was a light, sandy, alluvial loam and that it contained a very low percentage of moisture before irrigation, it is probable that little resistance was offered to the passage of the water through the soil and that most of it collected in the bottom of the tanks out of reach of the forces of evaporation. The moisture determinations made at the end of the experiments bear this out, as the soil in the bottoms of the tanks in both instances contained an average of 17 per cent of free water as against an average of 9.2 per cent in the surface soil.

The average loss from the uncultivated surfaces shows a loss equal to 1.51 inches of water, 25.2 per cent of the 6-inch irrigation. Approximately 50 per cent of this was lost in the first three days. The losses are small and quite uniform for the remainder of the experiment. The average loss from the uncultivated surfaces amounts to 1.09 inches, which is a saving of 0.42 inch, or 27.8 per cent of the loss from the uncultivated surfaces. Fifty-two per cent of this loss occurred in the first three days, the period before and immediately after irrigation. No increased loss is shown at the time of the second cultivation, the soil having dried out to a depth of at least 3 inches. The losses after the first week were very uniform, a slight decrease being shown in the last four days of the experiment.

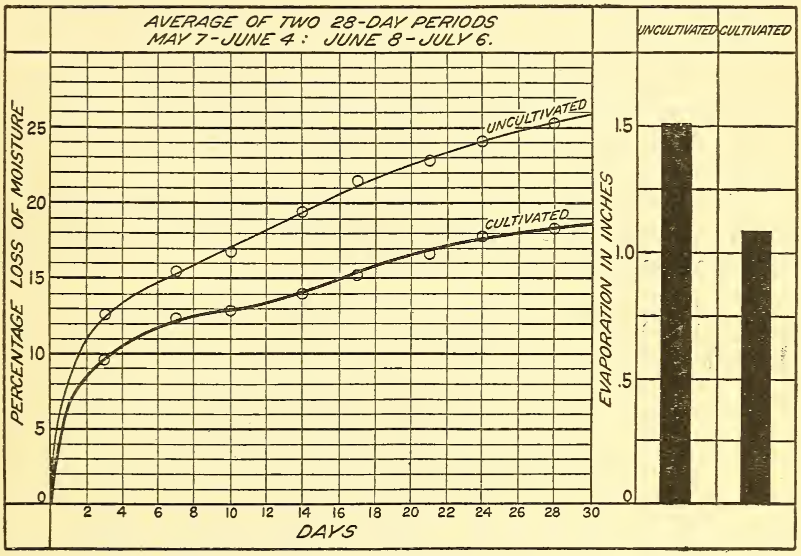

FIG. 11.—Average evaporation losses from cultivated and uncultivated tanks at Reno, Nev., May 7 to June 4 and June 8 to July 6, 1909.

RESULTS AT CALDWELL, IDAHO.

The site chosen for the experiments in Idaho was on the State substation farm at Caldwell, in the Boise Valley, 30 miles west of Boise. (See Pl. II, fig. 2, p. 24). The tanks were installed on a newly cleared tract which had never been plowed or irrigated. Mechanical analysis showed the surface soil to be a clay loam underlain with clay, which grades off into a sandy clay at a depth of 1 foot. This continued to a depth of 4 feet, where a stratum of cement gravel was encountered.

The first experiment ran from June 1 to June 29, and the second from July 3 to July 31. The usual procedure was followed in filling, irrigating, and weighing the tanks. As the tanks were filled, soil samples were taken, which showed the following moisture content—free water.

Moisture content of soil at beginning of experiments.

Depth.	June 1.	July 3.
	Per cent.	*Per cent.*
1 foot	3.35	5.77
2 feet	8.70	5.06
3 feet	8.14	6.38
4 feet	7.00	5.31
Mean	6.80	5.63

An average period of 20½ hours elapsed from the time of the beginning of the irrigation until the water disappeared from the surface of the soil. This long period was probably due to the compactness of the soil and its general clay texture, which greatly retarded the percolation. A period of approximately 72 hours elapsed in each case between irrigation and cultivation. This long period was due also to the character of the soil, which held the water close to the surface.

During the month of June thermometers were not available, and the atmospheric and soil temperatures given in the following table are the results of July observations only:

Temperature of air, water, and cultivated and uncultivated soil, and rainfall at Caldwell, Idaho (July 3–31, 1909).

Periods.	Days.	Atmospheric temperature.	Temperature of cultivated soil.[1]	Temperature of uncultivated soil.[1]	Temperature of water.[1]	Rainfall.[2]
		°F.	*°F.*	*°F.*	*°F.*	*Inch.*
First	3	79.0	69.3	71.2	70.5	0.01
Second	4	67.0	66.5	66.9	66.8	.01
Third	3	69.6	66.7	67.8	65.6	00
Fourth	4	73.5	69.4	70.9	68.8	00
Fifth	3	72.4	71.2	70.2	68.3	.09
Sixth	4	77.6	70.3	70.0	69.5	
Seventh	3	75.8	71.6	70.1	69.2	
Eighth	4	67.2	69.2	68.4	68.7	.03
Average	28	72.2	69.2	69.4	68.4	

[1] Taken at depth of 6 inches.

[2] Average of two periods—June 1–29; July 3–31.

The following table gives the average losses from a free-water surface and from cultivated and uncultivated tanks by three and four day periods:

Average evaporation losses from free-water surface and from cultivated and uncultivated surfaces at Caldwell, Idaho (June 1–29 and July 3–31, 1909).

Periods.	Days.	Loss from water surface.	Cultivated.				Uncultivated.			
			Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
Average weight of tanks at beginning of experiment, pounds	....	....	1,172.2		1,185		1,172		1,169	
Average loss:		*Inches.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*
First	3	1.15	20.40	21.7	20.25	21.6	22.00	23.4	22.50	23.9
Second	4	1.19	3.35	3.6	2.90	3.1	7.10	7.6	7.10	7.6
Third	3	.95	.65	.7	1.00	1.1	1.25	1.3	1.75	1.9
Fourth	4	1.42	.50	.5	.00	.0	1.00	1.1	.75	.8
Fifth	3	1.17	3.00	3.2	2.75	2.9	3.40	3.6	3.40	3.6
Sixth	4	1.50	1.75	1.9	1.35	1.4	1.75	1.9	1.35	1.4
Seventh	3	1.08	.25	.3	.25	.3	.25	.3	.25	.3
Eighth	4	1.35	.90	1.0	.90	1.0	1.00	1.1	.75	.8
Total	28	9.1	30.80	32.9	29.40	31.4	37.75	40.3	37.85	40.3
Equivalent loss in inches	....	....	....	1.91		....	....	2.42		....

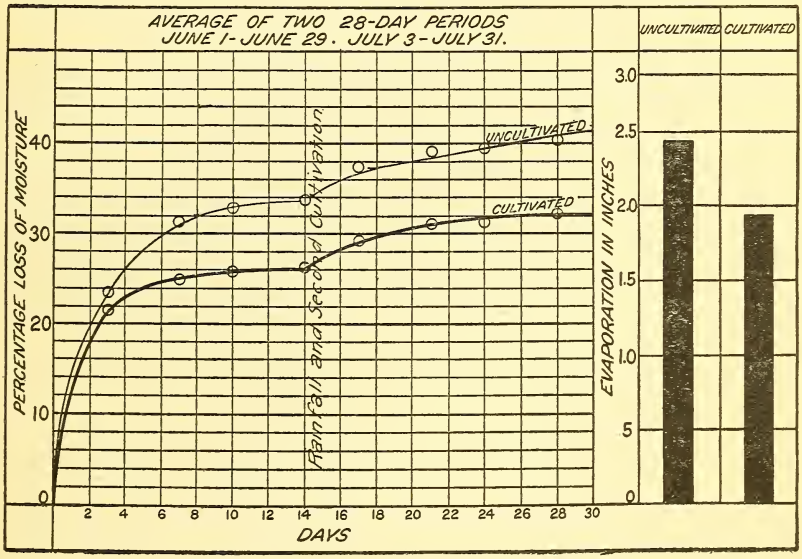

FIG. 12.—Average evaporation losses from cultivated and uncultivated tanks at Caldwell, Idaho, June 1-29 and July 3-31, 1909.

A comparison of the average losses from the cultivated and uncultivated surfaces, and the average losses for the different periods in percentages of the total irrigation, are shown in figure 12.

The table shows very heavy losses from both the cultivated and uncultivated surfaces and that a very large percentage of this occurred in the period immediately after irrigation. These heavy losses were due entirely to the character of the soil. This type of soil allows a very slow penetration of water, and therefore much of the water is held in the surface layer, which has a tendency to compact and run together because of its clay texture, thus producing heavy losses. The increase in loss in the fifth period is due partly to the rainfall, 0.09 inch, and partly to the second cultivation which was practiced in that period. The losses are in a ratio of 1.91 inches for the cultivated to 2.42 inches for the uncultivated surfaces, giving a saving of 21.2 per cent of the loss from an uncultivated surface. Sixty-seven and one-half per cent of the total loss from the cultivated tanks took place in the first three days after irrigation, while the uncultivated tanks lost 59 per cent of the total in the same period. The losses in the first three days were 21.6 per cent and 23.7 per cent of the 6-inch irrigation, respectively, for the cultivated and uncultivated surfaces. This is the only instance recorded where the evaporation from a soil surface in a three-day period is greater than the evaporation from a free-water surface and shows the necessity of early and thorough cultivation.

RESULTS AT AGRICULTURAL COLLEGE, N. MEX.

This experiment was carried on from May 4 to June 1 and from June 4 to July 2, using the same site and equipment as in the experiment with soil mulches the previous season. Unfortunately, no soil samples were taken for moisture determinations either at the beginning or at the end of the experiment. Other valuable data, such as the time between irrigation and cultivation and the time required in irrigation, are also lacking. A record of atmospheric temperature, humidity, wind velocity, evaporation, and rainfall was kept and the averages for the two periods are shown in the following table:

Average temperature, humidity, wind velocity, and rainfall at Agricultural College, N. Mex. (May 4 to June 1 and June 4 to July 2, 1909).

Periods.	Days.	Mean temperature.	Mean humidity.	Mean wind velocity per hour.	Rainfall.
		°F.	*Per cent.*	*Miles.*	*Inches.*
First	3	77.0	15.0	8.1	....
Second	4	72.0	16.0	8.4	....
Third	3	73.0	20.5	9.4	....
Fourth	4	74.0	25.0	8.4	....
Fifth	3	74.0	24.0	7.3	0.57
Sixth	4	76.0	23.0	8.4	....
Seventh	3	75.0	29.0	7.1	....
Eighth	4	75.5	28.0	8.9	....
Average	28	74.5	22.7	8.3	....

The following table and figure 13 give the average losses from a free-water surface and from the cultivated and uncultivated tanks by three and four day periods:

Average evaporation losses from free-water surface and from cultivated and uncultivated surfaces at Agricultural College, N. Mex.[1] *(May 4 to June 1 and June 4 to July 2, 1909).*

Periods.	Days.	Loss from water surface.	Cultivated.				Uncultivated.			
			Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
Average weight of tanks at beginning of experiment, pounds	....	....	1,441		1,406		1,442		1,446	
Average loss:		*Inches.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
First	3	1.35	11.57	12.3	12.51	13.3	11.57	12.3	10.05	10.7
Second	4	1.65	1.37	1.4	.91	1.0	2.73	2.9	2.28	2.4
Third	3	1.60	.99	1.1	1.59	1.7	2.62	2.8	2.05	2.2
Fourth	4	1.31	1.44	1.5	1.18	1.3	.91	1.0	1.63	1.7
Fifth	3	1.16	3.30	3.5	2.15	2.3	3.19	3.4	3.73	3.9
Sixth	4	1.38	1.01	1.1	.76	.8	2.20	2.3	1.33	1.4
Seventh	3	1.21	1.33	1.4	1.37	1.4	1.90	2.0	1.71	1.7
Eighth	4	1.47	.76	.8	.91	1.0	.61	.6	1.48	1.6
Total loss	28	11.13	21.77	23.1	21.38	22.8	25.73	27.3	24.25	25.6
Equivalent of average loss in inches	....	....	1.37				1.59			

[1] Actual losses from 27-inch tanks reduced to proportional losses from 23½-inch tanks.

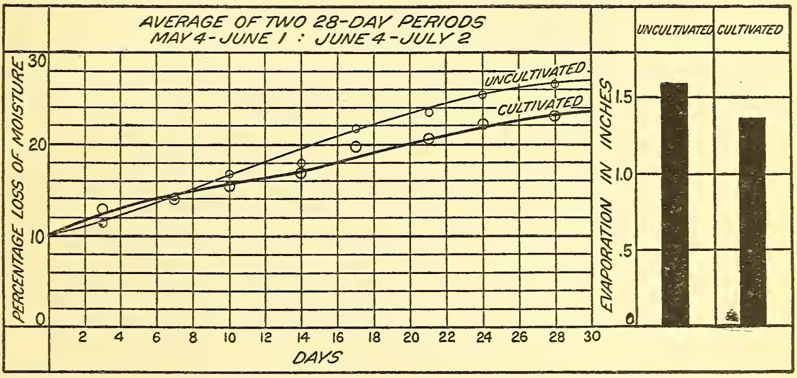

Fig. 13.—Average evaporation losses from cultivated and uncultivated tanks at Agricultural College, N. Mex., May 4 to June 1 and June 4 to July 2, 1909.

This table shows very little in favor of cultivation. The cultivated surface lost an equivalent of 1.37 inches of water; 22.8 per cent of the 6-inch irrigation and 55.8 per cent of this loss occurred in the first three days, probably before cultivation. The uncultivated soil lost 1.59 inches, which is 26.5 per cent of the 6-inch irrigation, and 43.2 per cent of this was lost in the first three days. The heavy losses in all of the tanks during the fifth period were due to the rainfall, 0.57 inch, during that period.

The total saving in favor of cultivation is very small, averaging for the two months only 13.8 per cent of the amount lost from the uncultivated surface. This small difference is due to the character of the soil which, it will be remembered, is a sandy loam intermixed with gravel. This light, sandy soil has a tendency to mulch and after the first few days the losses drop rapidly away and then remain constant for the remainder of the experiment. The temperatures, wind velocities, etc., are very constant, although the mean temperatures are very high, and a heavy constant evaporation from the water surface is produced throughout.

RESULTS AT BOZEMAN, MONT.

Owing to leaks which developed in the tanks after they were installed, the results of the first trial of this experiment had to be discarded and it was not until July 25 that the experiment was finally gotten under way. Analysis of the soil gave 17.8 per cent of free moisture, and for this reason 5 instead of 6 inches of water was applied. Over 24 hours elapsed from the time irrigation was commenced until it was finally finished and a period of 4 full days elapsed between irrigation and cultivation. At the end of the experiment, moisture determinations show an average of 22.5 per cent of free moisture, very evenly distributed through the soil in the tanks. Even with this heavy moisture content no free water seems to have collected in the bottoms of the tanks.

The following tables give the climatological data and the losses from the free-water surface and the cultivated and uncultivated surfaces by three and four day periods:

Temperature of air, water, and cultivated and uncultivated soils, wind velocity, and rainfall at Bozeman, Mont. (July 25 to Aug. 22, 1909).

Periods.	Days.	Mean atmospheric temperature.	Mean soil temperature uncultivated.	Mean soil temperature cultivated.	Mean water temperature.	Mean velocity of wind per hour.	Rainfall.
		°F.	*°F.*	*°F.*	*°F.*	*Miles.*	*Inches.*
First	3	60.0	68.5	68.0	....	11.4	....
Second	4	61.7	....	....	....	9.4	....
Third	3	64.8	....	....	....	8.3	0.36
Fourth	4	63.7	75.0	75.8	74.0	8.6	....
Fifth	3	62.1	78.5	73.3	74.3	11.7	.11
Sixth	4	68.0	70.7	72.7	76.0	9.5	.21
Seventh	3	67.2	76.0	76.5	73.5	8.8	.31
Eighth	4	67.2	79.0	75.0	77.0	8.3	....
Average	28	64.4	74.6	73.9	75.0	9.4	....

Evaporation losses from cultivated and uncultivated surfaces at Bozeman, Mont.[1] *(July 25 to Aug. 22, 1909.)*[2]

Periods.	Days.	Cultivated.				Uncultivated.			
		Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
Average weight of tanks at beginning of experiment, pounds		1,238		1,231		1,264.4		1,229.4	
Average loss:		*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
First	3	10.90	11.6	11.40	12.1	11.90	12.6	9.90	10.5
Second	4	4.75	5.3	3.50	3.7	6.50	6.9	5.75	6.1
Third	3	3.80	4.2	5.50	5.8	6.80	7.2	7.00	7.5
Fourth	4	3.25	3.5	4.00	4.3	5.00	5.3	5.75	6.1
Fifth	3	4.20	4.5	3.00	3.2	5.20	5.5	4.50	4.8
Sixth	4	1.50	1.6	2.50	2.7	2.05	2.2	1.80	1.9
Seventh	3	7.10	7.5	5.10	5.4	6.10	6.5	4.10	4.4
Eighth	4	1.50	1.6	.35	.4	3.25	3.5	5.80	6.2
Total	28	37.00	39.8	35.35	37.6	46.80	49.7	44.60	47.5
Equivalent of total loss in inches		2.30				2.92			

---

[1] Although only 5 inches (78.5 pounds) was applied, owing to the high percentage of moisture (17.8 per cent) in the soil at the beginning of the experiment, the precentages of loss have been based on a 6-inch irrigation.

[2] Total loss by evaporation from free-water surface for 28 days, 4.38 inches.

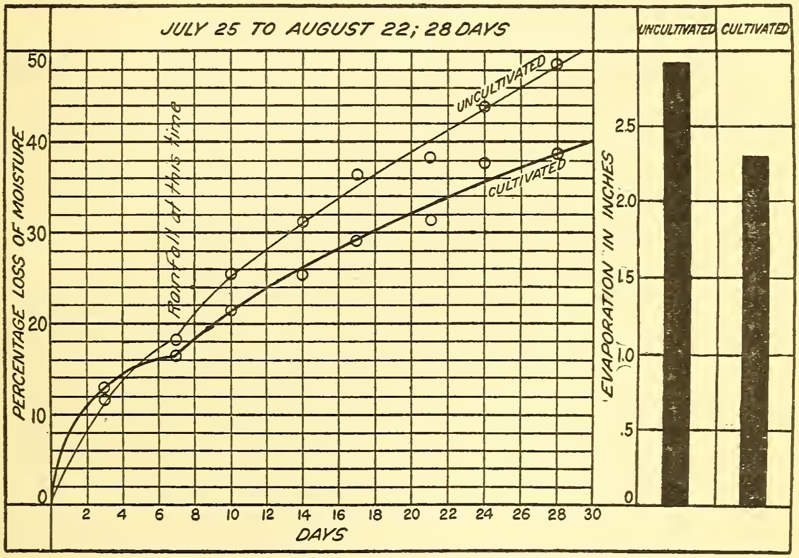

FIG. 14.—Evaporation losses from cultivated and uncultivated tanks at Bozeman, Mont., July 25 to August 22, 1909.

The total losses in inches and losses in percentage of a 6-inch irrigation by 3 and 4 day periods are shown in figure 14.

The most noticeable feature of these results is the enormous losses during every weighing period of the experiment, both from the cultivated and the uncultivated soils. These total losses amount to 2.30 inches and 2.92 inches, respectively, and show a saving of

21 per cent in the loss on the cultivated as compared with the uncultivated soil.

These heavy losses are due to two causes: First, to the very heavy percentage of free moisture in the soil before irrigation; and second, to the rainfall, the heavy losses in the third and seventh periods being due to the latter cause. The rainfall affected both cultivated and uncultivated soils alike, increasing the evaporation and decreasing the difference between the cultivated and uncultivated surfaces. It is nevertheless seen that 31.5 per cent of the total loss, including the rainfall losses from the cultivated soils, takes place before cultivation. The rainfall, which amounted to 0.99 inch, came in light showers and was equivalent to adding 15½ pounds of water to each tank. This 15½ pounds corresponds to 42.8 per cent of the total moisture lost from the cultivated and 33.9 per cent of that lost from the uncultivated tanks. Deducting the loss before cultivation (first period) and the probable loss of all the added rainfall from the total loss gives 9.52 pounds loss from the cultivated and 19.30 pounds loss from the uncultivated soil. This gives a better idea of the saving by cultivation.

RESULTS AT WILLISTON, N. DAK.

Equipment similar to that used at the other stations was installed in 1909 at the Williston substation, in Williams County in the extreme northwestern part of the State. Williston has an average elevation of 1,875 feet, with a temperature ranging from 107° F. to −59° F., and a mean of 39.4°. The average annual rainfall is 15.07 inches, about 10 inches of which falls during April, May, June, July, and August.

The soil, typical of the lands included in the United States reclamation project at Williston, is largely bench lands, and ranges from a sandy gumbo on the lower benches to a sandy loam on the upper benches. Very little alkali is found, and that only in a few spots.

The tanks were filled early in August and the test was continued for three weeks. At the end of this period the moisture content of each tank was equalized by adding the amount lost by evaporation during the three weeks. An additional 4-inch irrigation was then given, four of the tanks being cultivated as soon as the soil was sufficiently dry, and the weighings were continued for another three weeks. Analysis of soil samples taken at the time of filling shows that they contained the low average of 3.7 per cent moisture in the first 4 feet of soil.

During the six-week period of the experiment a total of 1.26 inches of rain fell and this, coupled with the 10 inches of water applied in irrigation, produced a constant heavy loss from both the cultivated and the uncultivated surfaces, and in the end only a slight advantage was shown in favor of cultivation.

The following data were obtained for the six-week period: Mean temperature, 69° F.; mean soil temperature, 61.4°; mean water temperature, 69.6°; total rainfall, 1.26 inches; evaporation from free-water surface, 4.21 inches; average loss from cultivated tanks, 56.4 pounds, equivalent to 3.59 inches; average loss from uncultivated tanks, 62.4 pounds, equivalent to 3.98 inches.

The following tables give the climatological data and the average losses from the several surfaces for the different periods of the two experiments:

Average temperature of air, soil, and water, and rainfall at Williston, N. Dak. (Aug. 4 to 24 and Aug. 24 to Sept. 14, 1909.)

Period.	Days.	Mean temperature.	Mean soil temperature.[1]	Mean water temperature.[1]	Rainfall.
		°F.	*°F.*	*°F.*	*Inches.*
First	3	70.9	64.0	71.3	0.18
Second	4	62.8	58.2	67.7	.17
Third	3	70.7	65.8	71.4	....
Fourth	4	67.7	58.2	72.0	.54
Fifth	3	67.8	61.3	69.7	....
Sixth	4	67.3	60.8	65.6	.37
Average	21	64.5	61.1	69.5	....

[1] Taken from depth of 3 inches.

Average evaporation losses from free-water surfaces and from cultivated and uncultivated surfaces at Williston, N. Dak. (Aug. 4 to 24 and Aug. 24 to Sept. 14, 1909).

Period.	Days.	Loss from water surface.	Cultivated.				Uncultivated.			
			Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
Average weight of tanks at beginning of experiment, pounds	....	....	1,042		1,040		1,050		1.010	
Average loss:		*Inches.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
First	3	0.62	11.15	11.9	12.45	13.2	11.55	12.3	9.45	10.0
Second	4	.83	3.85	4.1	2.65	2.8	4.35	4.6	3.75	4.0
Third	3	.56	3.00	3.2	4.10	4.4	4.95	5.3	3.40	3.6
Fourth	4	.74	3.50	3.7	2.25	2.4	4.10	4.4	4.60	4.9
Fifth	3	.57	2.30	2.4	3.80	4.1	6.35	6.8	5.70	6.1
Sixth	4	.89	4.45	4.7	3.70	3.9	2.30	2.4	2.00	2.1
Total	21	4.21	28.25	30.0	28.95	30.8	33.60	35.8	28.90	30.7
Equivalent of average total loss in inches	....	....	....	1.82		....	....	1.99		....

The total losses in inches and the losses in percentages of a 6-inch irrigation by 3 and 4 day periods are shown in figure 15.

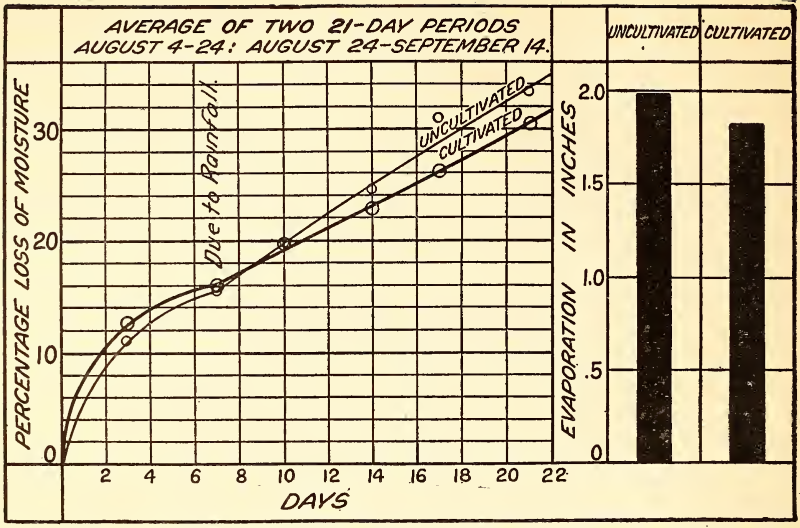

FIG. 15.—Average evaporation losses from cultivated and uncultivated tanks at Williston, N. Dak., August 4-24 and August 24 to September 14, 1909.

SUMMARY AND CONCLUSIONS.

The results of the observations from six of the seven stations [1] have been compiled into the accompanying table, showing average evaporation losses from soil and water, rainfall, mean wind velocity, humidity, and atmospheric temperatures for each three and four day period of the experiment:

Average mean temperature of soil, mean humidity and wind velocity, and average loss from free-water surface and from cultivated and uncultivated surfaces at the six stations, by three and four day periods.[2]

Period.	Days.	Mean temperature of air.	Mean humidity.[3]	Mean velocity of wind per hour.[4]	Loss from water surface.[5]	Cultivated.				Uncultivated.			
						Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
		°F.	*P. ct.*	*Miles.*	*Ins.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*	*Lbs.*	*P. ct.*
First	3	66.1	40.4	8.5	1.17	12.67	13.5	12.63	13.4	13.23	14.1	12.60	13.4
Second	4	62.9	38.8	8.0	1.29	3.31	3.5	2.72	2.9	5.79	6.2	5.81	6.2
Third	3	64.7	41.7	9.3	1.18	1.52	1.6	2.06	2.2	3.58	3.8	3.36	3.6
Fourth	4	65.2	51.6	7.9	1.08	1.39	1.5	1.10	1.2	2.25	2.4	2.81	3.0
Fifth	3	66.5	42.7	8.3	1.06	3.24	3.4	2.73	2.9	3.19	3.4	3.12	3.3
Sixth	4	68.7	43.8	9.0	1.33	.67	.7	.93	1.0	1.87	2.0	1.55	1.6
Seventh	3	67.5	42.4	8.2	1.22	1.96	2.1	1.41	1.5	2.17	2.3	1.66	1.8
Eighth	4	68.8	47.0	7.9	1.38	.80	.9	.68	.7	1.73	1.8	2.28	2.4
Average	28	66.3	43.8	8.4	......	......	......	......	......	......	......	......	......
Total for 28 days	......	......	......	......	9.71	25.56	27.2	24.26	25.8	33.81	36.0	33.19	35.3
Equivalent of total loss in inches	......	......	......	......	......	1.58				2.13			

---

[1] Williston, N. Dak., omitted, as experiments were run only 21 days.

[2] In compiling averages, the losses at Agricultural College, New Mexico station have been reduced to proportional losses from tanks of similar size to those used at other stations.

[3] Average of three stations: Davis, Cal.; Reno, Nev.; Agricultural College N. Mex.

[4] Average four stations: Davis, Cal.; Reno, Nev.; Bozeman, Mont.; and Agricultural College, N. Mex.

[5] Average four stations: Davis, Cal.; Reno, Nev.; Agricultural College, N. Mex.; and Caldwell, Idaho.

The average evaporation losses in pounds by three and four day periods and the total losses in inches for the different periods of the experiments are also shown in figure 16.

The average total losses shown by the above data are 2.13 inches from the uncultivated and 1.58 inches from the cultivated soils, being 35.5 and 26.3 per cent, respectively, of the total 6 inches used in irrigation. Thus it is seen that cultivation reduced the loss more than 25.8 per cent. Fifty-one per cent of the loss from the cultivated surface occurred in the first three days; that is, during the average period between irrigation and cultivation, while during the same period the uncultivated tanks lost 38.5 per cent of the total. The saving due to cultivation when figured in percentages is naturally low because of these heavy first losses. If the losses during the first three days in each case are disregarded, however, and only the losses after the first cultivation are considered, the saving due to cultivation averages 40 per cent of the loss from the uncultivated soil.

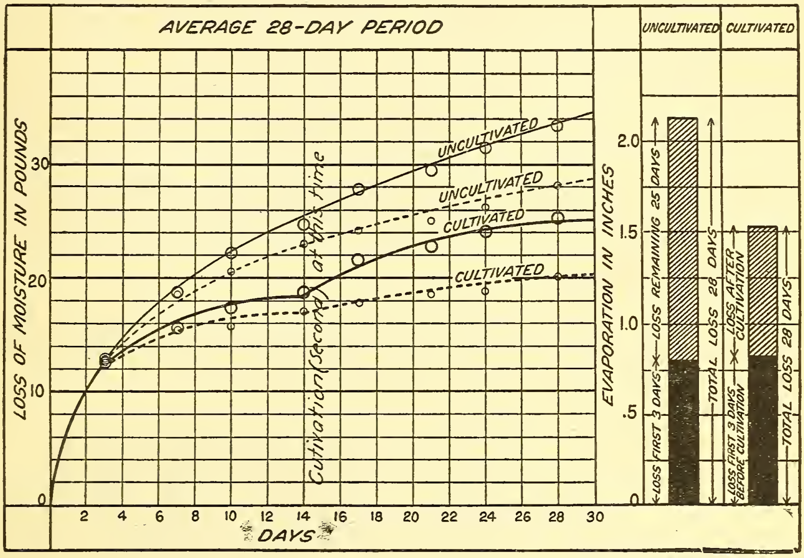

FIG. 16.—Average evaporation losses from cultivated and uncultivated tanks during first 28 days after irrigation; average of losses at six stations.

The most noteworthy feature of this experiment was the uniformly heavy losses immediately after irrigation. This emphasizes the necessity of early cultivation, especially in the heavier soils, where the percolation of moisture through the soil is slow and the moisture content of the surface soil is high. The actual saving of water may be small to the irrigator having an abundant water supply at hand, but it is well to remember that the saving of 0.5 to 1 inch of water per irrigation amounts to several inches during the season and often marks the dividing line between success and failure as regards the crop.

The value of deep mulches in checking evaporation and in improving the condition of the soil has been discussed under the previous experiment, and these advantages are directly applicable to cultivation as well, because it is by cultivation that the soil mulch is produced, the depth and fineness of the mulch depending entirely upon the depth, the manner, and the frequency of cultivation.

In figure 16 the solid lines represent the total loss in pounds from cultivated and uncultivated soils, and the dotted lines represent the same losses after the rainfall for the different periods has been deducted. The irregularities in the solid curves are no doubt due to the evaporation of the rainfall, and when this has been deducted more uniform curves result.

Both curves of the cultivated soils show a decided break after the fourteenth day, due to the increased evaporation from the fresh soil turned up by cultivation at that time. After this small increase in loss the curves drop back and the losses for the remainder of the experiment appear smaller than ever. The results obtained at each of these stations have been assembled for the sake of comparison in the following table:

Summary of temperature of air, soil, and water, humidity, wind velocity, rainfall, free water in soil, and losses from free-water surface and from cultivated and uncultivated tanks at the several stations.

Stations.	Number of trials.	Temperatures.				Humidity.	Average wind velocity per hour.	Total rainfall.	Free water in soil.	Evaporation from free-water surface.	Loss from cultivated soils.	Loss from uncultivated soils.	Saved by cultivation.
		Atmospheric.	Cultivated soil.	Uncultivated soil.	Water.								
		°F.	*°F.*	*°F.*	*°F.*	*P.ct.*	*Miles*	*In.*	*P.ct.*	*In.*	*In.*	*In.*	*P.ct.*
Sunnyside, Wash	1	65.2	71.3	74.3	70.9	......	......	0.00	6.00	7.25	1.47	2.47	40.3
Davis, Cal	2	64.5	......	75.7	73.2	49.8	9.3	.00	12.85	9.41	1.36	1.91	28.2
Reno, Nev	2	56.6	......	67.9	......	58.9	6.4	.39	8.88	8.49	1.09	1.51	27.8
Caldwell, Idaho	2	72.2	69.2	69.4	68.4	......	......	.14	6.21	9.81	1.91	2.42	21.0
Agricultural College, N. Mex	2	74.5	......	......	......	22.7	8.3	.57	......	11.13	1.37	1.59	13.8
Bozeman, Mont	1	64.4	73.9	74.6	75.0	......	9.4	.99	17.80	4.38	2.30	2.92	21.2
Average	....	66.2	71.5	72.4	72.9	43.8	8.4	.35	10.35	8.41	1.58	2.14	26.4

There are three factors which may be said to control the evaporation from soil surfaces: (1) The percentage of moisture in the soil; (2) the general character of the soil, its composition, compactness, and general texture; and (3) climatology, including temperatures, humidity, wind movement, etc. Of these the percentage of moisture in the soil again seems to have the most decided influence. The table above shows that the percentage saved by cultivation varies throughout with the rainfall, and consequently with the percentage of moisture in the top layer of soil. Thus in Washington and California, where no rain fell during the experiment, the effects of cultivation showed up to far better advantage than in Montana and New Mexico, where the initial percentage of moisture in the soil was large and the rainfall the greatest shown. Montana, with low temperatures and a small evaporation from a free-water surface, 4.38 inches, other things being equal, should give the least loss from soil surfaces. This was not the case, as the climatological effect was entirely overbalanced by the rainfall and moisture content of the soil before irrigation.

It is further noticeable that the best results were obtained from the heavier soils, which, when irrigated, have a tendency to compact and run together, affording an excellent opportunity for heavy losses from the uncultivated surfaces, and therefore showing a larger saving when cultivation is practiced. There is a tendency in light, sandy soils for the uncultivated surfaces to mulch themselves, and after the first few days following the irrigation the losses diminish very rapidly, and in the end little advantage is shown in favor of cultivation.

EFFECTS OF SHALLOW AND DEEP FURROW IRRIGATION.

The heavy evaporation losses from soil surfaces during the period between irrigation and cultivation exemplified in the foregoing experiments (see pp. 31–51) naturally led to the investigation of methods designed to check the heavy losses occurring before cultivation is possible. As stated formerly, these losses depend principally upon the percentage of moisture in the soil and to a lesser extent upon the character of the soil and the climate.

In localities where the available water supply is limited and where the duty of water is high, conditions have forced the irrigator to adopt methods of irrigation less wasteful of water than that of flooding the entire surface. This accounts in part for the introduction of furrows. Of late years, in orchard irrigation in particular, where this method is most in vogue, there has been a growing tendency toward fewer and deeper furrows with one heavy irrigation every four to six weeks, rather than a greater number of shallow furrows with a lighter irrigation at short intervals. The advantages and disadvantages of both of these methods are discussed in a former bulletin of this office,[1] but, generally speaking, the adoption of any one method is controlled almost entirely by local conditions, such as the available water supply, the character of the soil, and the character of the crop irrigated.

In order to gain some idea of the actual saving, if any, of deep irrigation over shallow irrigation, the part of the season of 1909 remaining after the other experiment was completed was devoted to experiments dealing with that subject. These experiments were carried on at each of the seven stations already described. Each of the eight tanks was refilled with fresh soil, replaced foot for foot in as nearly its natural position as possible, and tamped to its original compactness.

---

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 177.

After taking soil samples for moisture determinations the tanks were weighed and 94 pounds, equivalent to a 6-inch irrigation, was given to each of the tanks in the following manner: Tanks 1 and 2 were flooded over the entire surface; tanks 3 and 4 were irrigated in furrows 3 inches deep; tanks 5 and 6 were irrigated in furrows 6 inches deep; and tanks 7 and 8 were irrigated in furrows 9 inches deep. In applying the water the flow was so regulated that only the bottom of each furrow was wet, and the water at no time stood more than 2 inches deep in the furrows.

As soon after irrigation as the soil in any tank became sufficiently dry it was cultivated thoroughly to a depth of 6 inches. The tanks were weighed regularly twice a week for a period of four weeks, when they were emptied, refilled with fresh soil, and the test repeated during the next 28 days. In making the furrows and in cultivating after irrigation an effort was made to approach as nearly as possible actual field conditions.

As the local conditions, sites, and equipment have been described previously, mention will be made only of those cases where changes occurred.

RESULTS AT DAVIS, CAL.

The experiment was carried on during two periods—July 7 to August 7 and August 7 to September 7, 1909. In applying the water the flooded surfaces were covered continually to a depth of at least 1 inch, and an attempt was made to maintain a depth of one-half to 1 inch of water in the furrows.

The following preliminary observations were made:

Preliminary observations in tank experiments at Davis, Cal.

Method of irrigation.	Weight of soil before irrigation.	Free moisture in soil.	Length of irrigation.	Time between irrigation and cultivation.
	Pounds.	*Per cent.*	*Hours.*	*Hours.*
Flooded	945	5.6	3	74
3-inch furrows	941	5.5	4½	45
6-inch furrows	904	6.0	5¼	26½
9-inch furrows	888	5.2	5⅓	22

The different periods required to irrigate are due to the fact that in the deeper furrows a slower application was necessary to prevent the furrows from being destroyed. In each case cultivation was practiced as soon as the soil was sufficiently dry.

The average evaporation losses and climatology summary are shown in the following table:

Climatological data and the mean temperature of the soil and water at Davis, Cal. (average of two periods—July 7 to Aug. 7 and Aug. 7 to Sept. 7, 1909).

Periods.	Days.	Mean atmospheric temperature.	Mean soil temperature.[1]	Mean water temperature.[1]	Humidity.	Velocity of wind per hour.
		° F.	*° F.*	*° F.*	*Per cent.*	*Miles.*
First	3	68.5	82.1	77.0	47.8	8.53
Second	4	72.4	83.0	77.3	48.7	8.80
Third	3	72.2	83.5	78.5	45.6	7.07
Fourth	4	72.3	83.6	76.8	41.8	9.05
Fifth	5	71.6	83.0	77.7	43.3	7.73
Sixth	6	72.7	83.3	80.0	41.3	5.96
Seventh	3	71.1	83.1	78.0	45.3	7.28
Eighth	4	72.1	84.2	78.9	44.7	6.68
Total and average	32	71.8	83.3	78.1	44.4	7.85

[1] Taken at depth of 6 inches.

Evaporation losses from free-water surface and from surfaces irrigated by flooding and with furrows of different depths at Davis, Cal. (averages of two periods—July 7 to Aug. 7 and Aug. 7 to Sept. 7, 1909).

Periods.	Days.	Loss from water surface.	Flooded, tanks 1 and 2.		3-inch furrows, tanks 3 and 4.		6-inch furrows, tanks 5 and 6.		9-inch furrows, tanks 7 and 8.	
Average weight of tanks at beginning, pounds	....	....	1,039		1,036		1.010		982	
Average loss:		*Inches.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*
First	3	1.04	10.10	10.7	6.60	7.0	5.40	5.7	4.50	4.8
Second	4	1.48	4.40	4.7	3.15	3.3	3.25	3.5	2.50	2.7
Third	3	1.03	1.35	1.4	1.75	1.9	1.85	2.0	2.10	2.2
Fourth	4	1.54	1.25	1.3	1.60	1.7	1.00	1.1	.90	1.0
Fifth	5	1.00	1.50	1.6	2.15	2.3	1.75	1.9	1.40	1.5
Sixth	6	1.33	1.50	1.6	1.00	1.1	.90	1.0	1.10	1.2
Seventh	3	1.06	1.75	1.9	.40	.4	.60	.6	1.00	1.1
Eighth	4	1.31	.90	1.0	.25	.3	.60	.6	.40	.4
Total loss	32	9.79	22.75	24.2	16.90	18.0	15.35	16.4	13.90	14.9
Equivalent loss in inches	....	....	1.45		1.08		.98		.88	

The results for the first 28 days in the above table are shown graphically in figure 17.

In case of the 3-inch furrows it was observed that although no more than 1 inch in depth of water was maintained in the furrows during irrigation, the moisture rose until practically the whole of the surface was covered. The surface soil, however, contained much less moisture than that of the flooded tanks. With the 6-inch furrows, the moisture rose to the surface of the soil immediately adjoining the furrows, the moisture showing over about one-half of the area of the tanks. The moisture did not rise within 3 inches of the surface at any one place with the 9-inch furrows, and a perfectly dry mulch covered the entire surface with the exception of the wet part of the furrow, which averaged one-fourth of the soil surface. When the tanks containing the 9-inch furrows were cultivated, moist soil was turned up. In each case the percentage of moisture at a depth of 6 inches seemed to vary with the depth of the furrows. The moisture percentage in the top soil determined the period between irrigation and cultivation and the smaller percentage present accounts for the shorter period in the case of the deep-furrowed tanks. Of course the distribution of moisture in the top soil after irrigation depends upon the amount of water applied, the time required to apply it, the compactness and general texture of the soil, and the percentage of moisture present before irrigation.

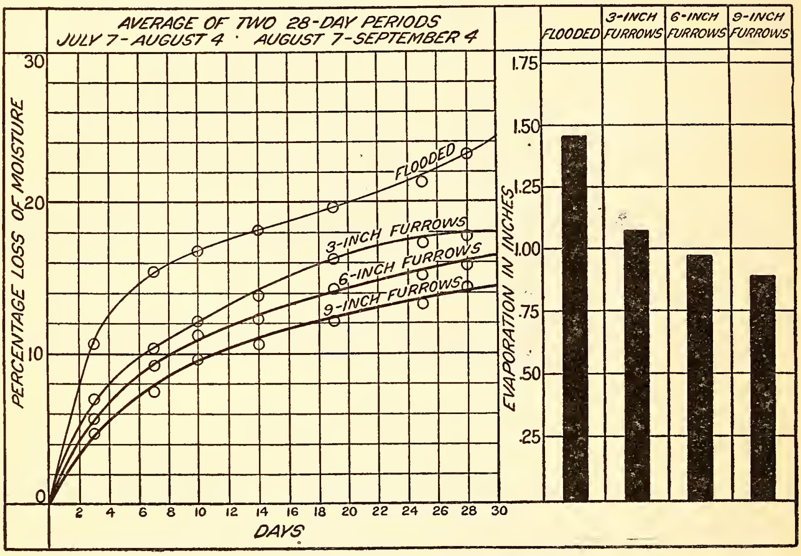

FIG. 17.—Average evaporation losses from tanks irrigated by flooding and with furrows of different depths at Davis, Cal., July 7 to August 4 and August 7 to September 4, 1909.

The table given above shows that the chief advantage in deep-furrow irrigation comes in the period immediately following the application of water. The total loss from the flooded surface was 1.45 inches, of which 45 per cent was lost during the first three days, the period between irrigation and cultivation. The application of the water in the 3, 6, and 9 inch furrows reduced the losses during the first three days 35, 47, and 55 per cent, respectively. The most noticeable feature in this experiment was the very uniform climatic conditions existing throughout, and the corresponding uniform losses from both soil and water surfaces. A range of but 4.2° was shown in the mean atmospheric temperatures, and but 4.7 per cent in the humidities, while a maximum daily variation of but 0.05 inch was recorded in the evaporation losses from a free-water surface.

RESULTS AT WILLISTON, N. DAK.

This test was started on September 15 and ended October 9, 1909. The same sort of tanks was used as at the other stations. The tanks were filled with fresh soil, after the usual method, and soil samples were taken which gave the following free-moisture content: Tanks 1 and 2, 3.50 per cent; tanks 3 and 4, 4.03 per cent; tanks 5 and 6, 4.40 per cent; tanks 7 and 8, 4.25 per cent.

Irrigation was commenced at 7.30 a. m. September 15, and continued six hours, the water being allowed to run slowly into the furrows, the intention being to approach as nearly as possible the natural field conditions. Only a 3-inch irrigation, 47 pounds, was applied at this time. As soon as the irrigation was completed the furrows were filled with dry soil, but the tanks were not cultivated until three days later. On September 25, another irrigation of 2 inches, 31.4 pounds, was given in a four-hour period, the furrows were refilled immediately, and a 6-inch cultivation given at the end of three days.

The records of the atmospheric, water, and soil temperatures, and the rainfall during the experiment are given in the following table:

Mean temperature of air, water, and soil and the rainfall at Williston, N. Dak., Sept. 15 to Oct. 9, 1909.

Period.	Mean atmospheric temperature.	Mean water temperature.	Mean soil temperature.[1]	Rainfall.
	°F.	*°F.*	*°F.*	*Inches.*
Sept. 15–18	60.0	60.8	51.3	
Sept. 18–21	57.6	57.8	49.8	
Sept. 21–25	49.2	52.8	39.9	0.36
Sept. 25–28	62.6	57.5	48.5	
Sept. 28–Oct. 2	64.2	60.8	52.4	
Oct. 2–5	55.4	55.3	48.0	
Oct. 5–9	58.0	53.5	43.0	
Average 24 days	57.6	56.8	47.3	

[1] Taken at depth of 3 inches at 8 a. m.

The losses by evaporation from the free-water surface and the several tanks are given in the table following by three and four day periods.

Evaporation losses from free-water surface and from surfaces irrigated by flooding and with furrows of different depths, Williston, N. Dak., Sept. 15 to Oct. 9, 1909.

Period.	Loss from water surface.	Flooded, tanks 1 and 2.		3-inch furrows, tanks 3 and 4.		6-inch furrows, tanks 5 and 6.		9-inch furrows, tanks 7 and 8.	
Average weight of tanks at beginning, pounds	....	1,030.0		1,033.2		1,020.8		1,010.5	
Average loss:	*Inches.*	*Lbs.*	*Per ct.*[1]	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
Sept. 15–18	0.485	4.85	10.3	1.95	4.1	2.35	5.0	1.95	4.1
Sept. 18–21	.556	4.25	9.0	1.50	3.2	1.50	3.2	1.75	3.7
Sept. 21–25	.360	5.90	12.6	4.40	9.4	2.90	6.2	3.15	6.7
2-inch irrigation.									
Sept. 25–28	.444	7.15	8.5	3.40	4.0	.45	.5	.40	.6
Sept. 28–Oct. 2	.749	4.50	5.4	3.25	3.9	1.70	2.0	.75	.9
Oct. 2–5	.480	3.50	4.2	2.00	2.4	1.25	1.5	1.25	1.5
Oct. 5–9	.526	1.75	2.1	1.25	1.5	1.50	1.8	.50	.6
Total loss	3.600	31.90	....	17.75	....	11.65	....	9.75	....
Equivalent loss in inches	....	2.03		1.13		0.74		0.62	

[1] The percentage of loss for the first 10 days is figured on a basis of 47 pounds (3-inch irrigation), that of the other periods and total loss on a basis of 84 pounds (5-inch irrigation plus 0.36 inch rainfall).

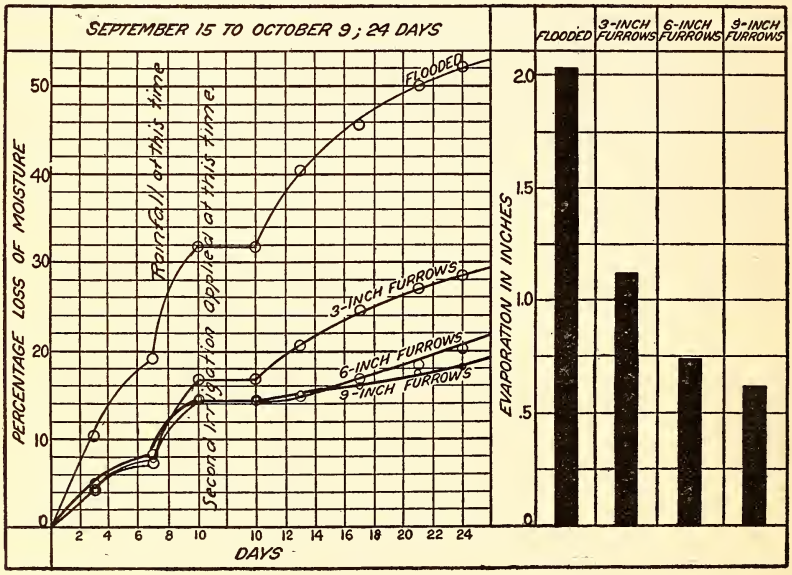

FIG. 18.—Evaporation losses from tanks irrigated by flooding and with furrows of different depths at Williston, N. Dak., September 15 to October 9, 1909.

The total losses and the percentages of the losses of the total irrigation by 3 and 4 day periods are shown graphically in figure 18.

Although the method of procedure varied considerably from that of the other stations, nevertheless, interesting results were obtained. The heavy losses in all of the tanks from September 21 to 25 were due to the rainfall of 0.36 inch in that period. The loss from the flooded surfaces during this period almost equaled the evaporation loss from a free-water surface, while in the three days succeeding the 2-inch irrigation the same tanks showed a loss of 0.01 inch greater than that from a free-water surface. These results show that the controlling factor in evaporation from soils is the content of free moisture in the surface layer of soil.

The first losses from the tanks which were furrowed were comparatively small, due to the furrows being filled with dry soil. The smallness of the losses was most noticeable after the second irrigation of September 25, at which time the losses from the 6 and 9 inch furrows showed no increase until after cultivation had been practiced.

The total loss from the flooded surface was 2.03 inches, which was over 56 per cent of the loss from a free-water surface. The application of the water in 3, 6, and 9 inch furrows prevented 44.2, 62.5, and 69.5 per cent, respectively, of the loss from the flooded surfaces.

RESULTS AT RENO, NEV.

This experiment extended through two periods of 28 days each—July 8 to August 5, and August 10 to September 7, 1909. The irrigation in each case continued seven and one-half to eight hours, and the flow was so regulated that water was kept standing in all of the furrows during the entire period of application. Within one-half hour after the completion of the irrigation the tanks irrigated with 6 and 9 inch furrows were cultivated to a depth of 6 inches and 24 hours later the other tanks were cultivated. No rain fell during July, but toward the last of August 0.1 inch was recorded and consequently on September 2 all tanks were given a 6-inch cultivation, but the rainfall was so slight that no appreciable effect was noticeable in the results.

Soil analyses of the samples taken when the tanks were filled gave the following moisture percentages: July 8: Tanks 1 and 2, 7; tanks 3 and 4, 8.7; tanks 5 and 6, 8.76; tanks 7 and 8, 9.40. August 10: Tanks 1 and 2, 5.67; tanks 3 and 4, 7; tanks 5 and 6, 8.78; tanks 7 and 8, 8.22.

The following table, based on the averages of the two periods, gives the climatological data and the mean water and soil temperatures:

Climatological data and the mean water and soil temperatures for Reno, Nev. (average of two periods—July 8 to Aug. 5 and Aug. 10 to Sept. 7, 1909).

Periods.	Days.	Mean atmospheric temperature.	Mean soil temperature.[1]	Mean water temperature.	Humidity.	Velocity of wind per hour.	Rainfall.
		°F.	*°F.*	*°F.*	*Per cent.*	*Miles.*	*Inches.*
First	3	64.6	78.3	76.2	60.0	5.90	
Second	4	66.2	78.8	76.0	44.1	5.35	
Third	3	67.0	79.8	74.7	50.3	6.12	
Fourth	4	68.6	78.4	75.2	44.3	5.90	
Fifth	3	64.1	80.8	75.3	33.0	6.90	
Sixth	4	64.3	79.7	74.7	27.0	4.72	0.05
Seventh	3	65.2	81.6	77.8	29.1	5.12	.05
Eighth	4	63.4	84.7	77.6	25.1	5.40	
Average	28	65.5	80.4	75.9	38.2	5.63	

[1] Taken at depth of 6 inches.

The following table gives the average evaporation from the free-water surface and the average losses from the several tanks in pounds and in percentage of total amount applied:

Evaporation losses from free-water surface and from surfaces irrigated by flooding, and with furrows of different depths at Reno, Nev. (average of two periods—July 8 to Aug. 5 and Aug. 10 to Sept. 7, 1909).

Periods.	Days.	Loss from water surface.	Flooded, tanks 1 and 2.		3-inch furrows, tanks 3 and 4.		6-inch furrows, tanks 5 and 6.		9-inch furrows, tanks 7 and 8.	
Average weight of tanks at beginning, pounds			1,326.5		1,286.5		1,263.5		1,279.0	
Average loss:		*Inches.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
First	3	1.17	8.15	8.7	5.30	5.6	2.60	2.8	1.20	1.3
Second	4	1.51	1.95	2.1	2.00	2.1	1.75	1.9	1.20	1.3
Third	3	1.37	2.30	2.4	1.40	1.5	1.00	1.1	1.15	1.2
Fourth	4	1.66	1.05	1.1	.70	.7	1.00	1.1	.80	.9
Fifth	3	1.24	.70	.7	1.45	1.6	1.60	1.7	.85	.9
Sixth	4	1.61	.75	.8	1.45	1.6	1.40	1.5	1.05	1.1
Seventh	3	1.08	.90	1.0	1.40	1.5	1.40	1.5	1.45	1.6
Eight	4	1.49	.75	.8	.65	.7	.75	.8	1.00	1.1
Total loss	28	11.13	16.55	17.6	14.35	15.3	11.50	12.4	8.70	9.4
Equivalent loss in inches			1.05		.91		.73		.55	

The data contained in these tables are shown graphically in figure 19.

These results compare very favorably with those obtained at the California station, although a greater advantage is shown in favor of the deeper furrows. At each of these two stations very uniform temperatures were recorded, which alone accounts for the uniformity in the evaporation from soil and water surfaces. The rainfall was not heavy enough to materially affect the losses, and the percentage of moisture in the soil was small enough to keep the evaporation within reasonable limits. The entire advantage shown in furrow irrigation in this case appears in the losses during the first three days after irrigation, and the decrease in the losses varies uniformly with the increasing depth of the furrows. Forty-nine and two-tenths per cent of the total loss from the flooded soils occurs in the first three days, and the use of 3, 6, and 9 inch furrows saved 13.3, 30.5, and 47.6 per cent, respectively, of the total loss from the flooded surface in 28 days. This seems to indicate that for such soil the practical limit of the depth of the furrow lies between 6 and 9 inches.

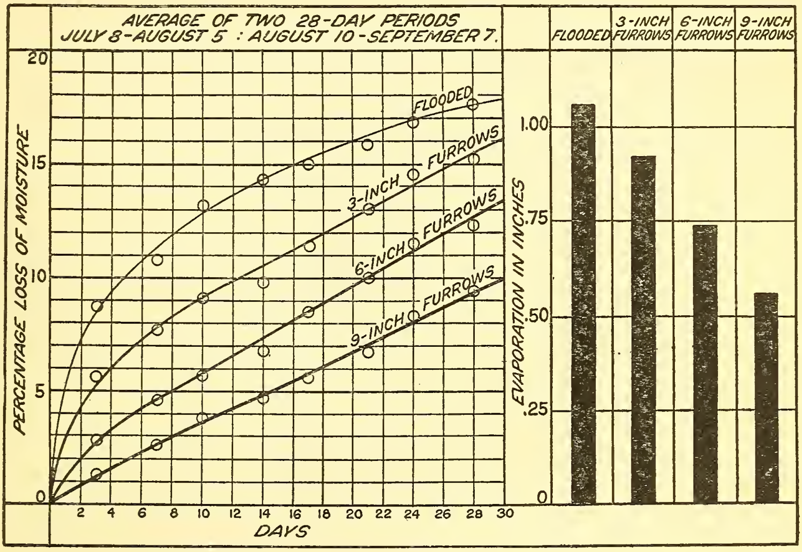

Fig. 19.—Average evaporation losses from tanks irrigated by flooding and with furrows of different depths at Reno, Nev., July 8 to August 5 and August 10 to September 7, 1909.

RESULTS AT BOZEMAN, MONT., AGRICULTURAL COLLEGE, N. MEX., AND SUNNYSIDE, WASH.

The experiment extended through two months at each of these stations, but in no case was any noticeable advantage observed in favor of furrow irrigation. Rainfall interfered with the experiments and entirely counterbalanced the effect of deep irrigation by destroying the mulches created by cultivation and thus allowing an almost constant heavy evaporation. This fact is shown in the table following, which gives the rainfall, the evaporation from a water surface, and the average losses in pounds from the several pairs of tanks irrigated in the different ways.

Rainfall, evaporation from free-water surface, and from surfaces irrigated with furrows of different depths at Bozeman, Mont., Agricultural College, N. Mex., and Sunnyside, Wash.

Station.	Date.	Rainfall.	Loss from water surface.	Flooded surface.	3-inch furrows.	6-inch furrows.	9-inch furrows.
		Inches.	*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Agricultural College, N. Mex.	July 20 Aug. 31	1.56	17.90	47.0	54.5	53.0	55.0
	Sept. 3 Oct. 1	1.12	7.70	38.5	39.5	37.0	36.5
Bozeman, Mont.	Aug. 25 Sept. 27	5.45	5.31	54.0	52.2	50.7	43.4
Sunnyside, Wash.	June 25 July 27	1.07	9.65	24.5	24.75	25.25	25.25

SUMMARY OF RESULTS AT RENO, NEV., AND DAVIS, CAL.

The results of the observations at the Nevada and California stations have been combined into the following tables:

Summary of climatological data at Davis, Cal., and Reno, Nev. (average of tables on pp. 53 and 58).

Period.	Days.	Mean maximum temperature.	Mean minimum temperature.	Humidity.	Mean wind velocity per hour.
		° F.	*° F.*	*Per cent.*	*Miles.*
First	3	90.0	43.2	53.9	7.22
Second	4	95.3	43.2	46.4	7.07
Third	3	93.3	45.8	48.0	6.60
Fourth	4	93.8	47.2	43.0	7.48
Fifth	3	91.6	44.0	38.2	7.32
Sixth	4	91.6	44.5	34.2	5.34
Seventh	3	88.5	47.8	37.2	6.20
Eighth	4	90.1	45.3	35.0	6.04
Average	28	91.9	44.8	41.7	6.64

Summary of evaporation losses from free-water surface and from surfaces irrigated by flooding and with furrows of different depths at Davis, Cal., and Reno, Nev. (averages of tables on pp. 53 and 58).

Periods.	Days.	Loss from water surface.	Flooded, tanks 1 and 2.		3-inch furrows, tanks 3 and 4.		6-inch furrows, tanks 5 and 6.		9-inch furrows, tanks 7 and 8.	
Average weight of tanks at beginning, pounds			1,182.7		1,145.0		1,136.7		1,130.5	
Average loss:		*Inches.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
First	3	1.10	9.14	9.7	5.95	6.3	4.00	4.3	2.85	3.0
Second	4	1.50	3.17	3.4	2.57	2.7	2.50	2.7	1.85	2.0
Third	3	1.20	1.83	2.0	1.58	1.7	1.43	1.5	1.63	1.7
Fourth	4	1.60	1.15	1.2	1.15	1.2	1.00	1.1	.85	.9
Fifth	3	1.12	1.10	1.2	1.80	1.9	1.68	1.8	1.12	1.2
Sixth	4	1.47	1.12	1.2	1.22	1.3	1.15	1.2	1.08	1.2
Seventh	3	1.07	1.32	1.4	.90	1.0	1.00	1.1	1.22	1.3
Eighth	4	1.40	.82	.9	.45	.5	.68	.7	.70	.7
Total loss	28	10.46	19.65	21.0	15.62	16.6	13.44	14.4	11.30	12.0
Equivalent loss in inches			1.25		.99		.86		.72	

The data given in the above table are shown graphically by figure 20.

This summary indicates that practically all of the saving in furrow irrigation was in the first week after the water had been applied, and it will be seen that after this period the curves in the diagram parallel each other for the remainder of the experiment, showing that the average losses for the different furrows were the same. In combining results such as these it is impossible to account for irregularities in the points of the different curves.

The average time of cultivation after irrigation was as follows: Flooded surface, 52 hours; 3-inch furrows, 36 hours; 6-inch furrows, 7 hours; 9-inch furrows, 12 hours. But even had these periods been the same a large difference in the losses by evaporation would still have existed, due to the varying percentage of moisture in the surface soil.

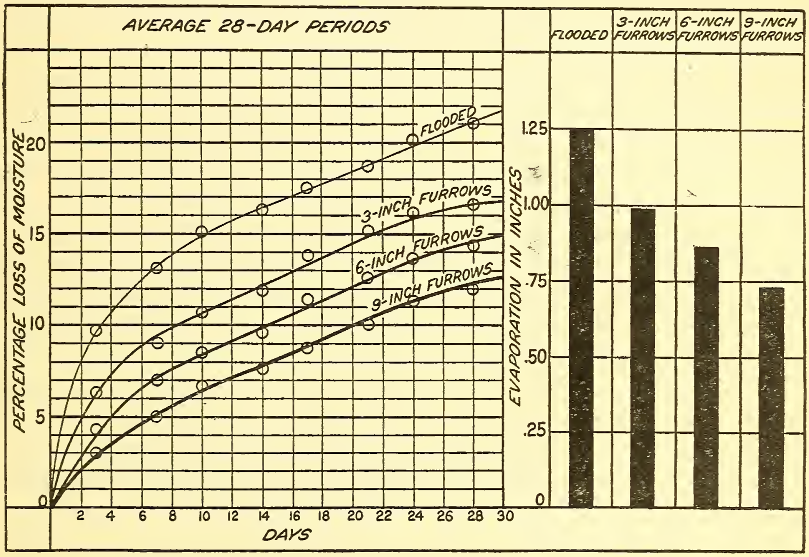

FIG. 20.—Average evaporation losses from tanks irrigated by flooding and with furrows of different depths at Davis, Cal., and Reno, Nev.

The loss from the flooded surface in the same period between irrigation and cultivation was 0.58 inch, or 46 per cent of the total loss during the 28 days. The 3, 6, and 9 inch furrows lost 0.38 inch, 0.25 inch, and 0.18 inch, respectively, during this same period. The table following shows the average amounts of water saved in a 28-day period at these two stations by the use of furrows of different depths.

Losses by evaporation and saving resulting from use of furrows of various depths.

	Loss by evaporation.	Amount saved over free-water surface.		Amount saved over flooded surface.		Amount saved over surface irrigated with 3-inch furrows.		Amount saved over surface irrigated with 6-inch furrows.	
	Inches.	*Inches.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*
Water surface	10.46								
Flooded	1.25	9.21	88.0						
3-inch furrows	.98	9.48	90.6	0.27	21.6				
6-inch furrows	.86	9.60	91.8	.39	31.2	0.12	12.2		
9-inch furrows	.72	9.74	93.0	.53	42.4	.26	26.5	0.14	16.3

EXPERIMENTS OF 1910.

In order to determine the actual losses from soil surfaces when soil is cultivated to different depths the following experiment was planned to extend through May and June, 1910, at each of the stations where experiments were made during two preceding seasons. The same sites and equipment were used throughout as in 1908 and 1909, and the same care was taken in filling the tanks to secure typical soil and to place it in the tanks in its natural position, foot for foot. As a rule there was just enough moisture in the soil to germinate the seed. As soon as the tanks were filled irrigation was practiced, the depths varying with the local conditions at the several stations, such as the amount of moisture in the soil before irrigation, the probable rainfall during the experiment, etc. In all cases the flooding method of irrigation was used, the soil in each of the tanks being kept entirely covered with water until the irrigation was completed. As soon as the top layer was sufficiently dry the soil in the different tanks was cultivated to the following depths: Tanks 1 and 2, no cultivation; tanks 3 and 4, 2-inch cultivation; tanks 5 and 6, 4-inch cultivation; tanks 7 and 8, 6-inch cultivation.

The same plan of cultivation was also followed as closely as practicable after each rain. Weighings were made at least twice a week and at each of the stations the usual observations of temperatures, humidities, wind velocities, and evaporation from a water surface were made.

RESULTS AT DAVIS, CAL.

The tanks were filled early in May and the experiment gotten under way May 3. A 6-inch irrigation was given in each case, and cultivation was practiced as soon as the soil was sufficiently dry. As the tanks were filled, soil samples were taken and their free-moisture content determined. The period of irrigation and the period between irrigation and cultivation were noted in each case.

Weighings were made every other day during the first 10 days, and twice a week for the remainder of the 28 days. At the end of this period the tanks were emptied, immediately refilled, and the experiment repeated during the next 28 days, beginning June 4.

The data secured in these preliminary observations, taken at the beginning of each of the experiments, are shown in the following table:

Preliminary observations at beginning of each of the experiments at Davis, Cal.

	Weight of soil.		Time required for 6-inch irrigation.		Time between irrigation and cultivation.		Percentage of free moisture in soil.	
	May 3.	June 4.	May.	June.	May.	June.	May 3.	June 4.
	Pounds.	*Pounds.*	*H. m.*	*H. m.*	*Days.*	*Hours.*	*Per ct.*	*Per ct.*
Tank No. 1	1,232	1,163	9 20	2 50	....	....	13.7	7.8
Tank No. 2	1,228	1,163	8 55	2 45	....	....	13.7	7.8
Tank No. 3	1,246	1,152	34 20	2 50	5	67	11.5	8.2
Tank No. 4	1,196	1,148	7 30	4 45	4	67	11.5	8.2
Tank No. 5	1,188	1,162	5 00	4 50	4	67	11.6	7.4
Tank No. 6	1,203	1,168	5 15	4 50	4	67	11.6	7.4
Tank No. 7	1,198	1,157	5 25	4 00	4	67	13.7	8.4
Tank No. 8	1,219	1,165	7 10	4 20	4	67	13.7	8.4

When the tanks were emptied at the end of each experiment, samples were again taken for moisture analysis. In each case tanks 1 and 2 had baked dry and sun-cracked to a depth of 1 to 1.5 inches. Below this depth the moisture gradually graded off until at 4 inches a uniform condition existed, and below the first foot the eye could not detect any variation in the condition of the soil. The soil in tanks 3 and 4 had dried completely through the 2-inch mulch and slightly into the soil below, while the 4 and 6 inch mulches were completely dry for a depth of 1.5 inches. Below the first foot the distribution and degree of moisture seemed to be the same as found in the uncultivated tanks.

The following table shows the even distribution of moisture, as shown from moisture determinations of samples taken as the tanks were emptied:

Distribution of moisture in soil at the end of the experiments.

Depths.	Tanks 1 and 2.		Tanks 3 and 4.		Tanks 5 and 6.		Tanks 7 and 8.	
	May 31.	July 2.	May 31.	July 2.	May 31.	July 2.	May 31.	July 2.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1 foot	16.00	12.5	14.90	15.3	17.10	14.9	16.70	15.6
2 feet	18.70	11.7	17.30	18.1	16.60	16.1	18.50	17.4
3 feet	19.40	16.6	19.35	18.0	20.20	16.6	20.00	17.7
4 feet	22.20	17.5	19.70	18.4	20.40	18.1	20.50	17.8
Mean	19.08	14.6	17.81	17.5	18.60	16.4	18.93	17.1

The temperature of the air, water, and soil, and the wind velocity during each of the periods covered by the two experiments, are given in the following tables:

Mean temperature of air, water, and soil, and the mean wind velocity at Davis, Cal., May 3–31, 1910.

Period.	Mean atmospheric temperature.	Mean water temperature.[1]	Mean soil temperature.[1]	Mean wind velocity per hour.
	°*F.*	°*F.*	°*F.*	*Miles.*
May 3–5	52.6	65.8	65.0	8.14
May 5–7	57.8	70.6	68.3	4.75
May 7–9	65.5	77.9	74.3	6.56
May 9–11	63.7	70.9	71.5	8.53
May 11–13	63.7	76.0	74.8	5.75
May 13–16	67.7	73.3	75.6	20.00
May 16–20	67.5	73.8	76.7	10.90
May 20–23	60.5	72.6	76.6	6.03
May 23–27	64.8	76.1	78.0	8.52
May 27–31	75.2	80.2	81.7	7.60
Average for 28 days	65.1	74.3	75.4	87.9

[1] Taken at a depth of 6 inches.

Mean temperature of air, water, and soil, and the mean wind velocity at Davis, Cal., June 4 to July 2, 1910.

Period.	Mean atmospheric temperature.	Mean water temperature.[1]	Mean soil temperature.[1]	Mean wind velocity per hour.
	°*F.*	°*F.*	°*F.*	*Miles.*
June 4–6	62.3	72.5	79.6	11.62
June 6–8	60.6	73.0	78.9	8.88
June 8–10	69.7	80.2	82.8	7.54
June 10–13	65.2	73.0	79.2	9.45
June 13–16	60.9	72.8	79.2	12.03
June 16–20	62.3	73.1	79.0	11.36
June 20–23	78.5	74.1	78.9	8.00
June 23–27	74.5	81.0	82.6	8.14
June 27–July 2	63.9	76.7	83.7	10.00
Average for 28 days	66.7	75.4	80.7	9.74

[1] Taken at a depth of 6 inches.

The tables following give the losses of evaporation from a free-water surface and from the tanks cultivated to different depths for the periods covered by the two experiments.

Average losses by evaporation from free-water surface and from surfaces cultivated to different depths, at Davis, Cal., May 3–31, 1910.

Periods.	Loss from water surface.	No cultivation, tanks 1 and 2.		2-inch cultivation, tanks 3 and 4.		4-inch cultivation, tanks 5 and 6.		6-inch cultivation, tanks 7 and 8.	
Average weight of tanks May 3, pounds	....	1,230		1,221		1,195.5		1,211.5	
Average loss:	*Inches.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*
May 3– 5	0.265	4.50	4.8	5.00	5.3	4.50	4.8	5.00	5.3
May 5– 7	.435	6.50	6.9	6.75	7.2	7.50	8.0	7.00	7.4
May 7– 9	.460	6.75	7.2	4.75	5.0	3.00	3.2	3.50	3.7
May 9–11	.270	2.75	2.9	2.75	2.9	1.25	1.3	1.00	1.1
May 11–13	.430	2.00	2.1	1.25	1.3	1.00	1.1	1.00	1.1
May 13–16	1.340	2.75	2.9	1.75	1.9	1.00	1.1	.75	.8
May 16–20	1.090	2.50	2.7	1.00	1.1	1.25	1.3	1.25	1.3
May 20–23	.905	1.75	1.9	1.50	1.6	.50	.5	1.25	1.3
May 23–27	.940	2.25	2.4	3.50	3.7	3.00	3.2	1.25	1.3
May 27–31	.960	5.75	6.1	4.00	4.3	3.00	3.2	2.50	2.7
Total, 28 days	7.095	37.50	39.9	32.25	34.3	26.00	27.7	24.50	26.00
Equivalent of total loss in inches	....	2.39		2.05		1.65		1.56	

Evaporation losses from free-water surface and from surfaces cultivated to different depths at Davis, Cal., June 4 to July 2, 1910.

Periods.	Evaporation from free-water surface.	No cultivation, tanks 1 and 2.		2-inch cultivation, tanks 3 and 4.		4-inch cultivation, tanks 5 and 6.		6-inch cultivation, tanks 7 and 8.	
Average weight of tanks June 4, pounds	....	1,163		1,150		1,165		1,161	
Average loss:	*Inches.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*	*Pounds.*	*Per ct.*
June 4– 6	0.795	11.25	12.0	8.50	9.0	5.50	5.8	8.50	9.1
June 6– 8	.515	2.50	2.7	3.50	3.7	5.00	5.3	4.50	4.8
June 8–10	.550	5.75	6.1	3.50	3.7	.75	.8	1.00	1.1
June 10–13	.815	2.50	2.7	1.75	1.9	1.00	1.1	.25	.3
June 13–16	.820	2.50	2.7	1.75	1.9	1.75	1.9	1.25	1.3
June 16–20	1.215	2.25	2.4	2.00	2.1	1.00	1.1	.50	.5
June 20–23	.905	2.00	2.1	.50	.5	.25	.3	.25	.3
June 23–27	1.375	2.25	2.4	.75	.8	1.25	1.3	.50	.5
June 27–July 2	1.387	1.25	1.3	.75	.8	.25	.3	.00	.0
Total, 28 days	8.377	32.25	34.4	23.00	24.4	16.75	17.9	16.75	17.9
Equivalent of total loss in inches	....	2.05		1.46		1.06		1.06	

The averages of the total losses for each sort of surface during the two experiments and the average variations in the percentages of moisture lost during each period of the two experiments are shown graphically in figure 21.

The results given in the above tables present the same general features—a decided advantage in cultivation up to a depth of 4 inches, beyond which the saving is so small that no conclusion can be drawn.

In the evaporation from a water surface during the two experiments 1.28 inches more is shown in the second than in the first experiment, caused by higher temperatures and climatic conditions favoring heavier evaporation. On the other hand, the losses from the soil surfaces are just reversed, the variation undoubtedly being caused mainly by the difference in moisture content of the soil before irrigation, as shown on page 63, which overbalanced the effect of the climate as a factor in evaporation.

The average evaporation loss for these two periods from an uncultivated soil surface was 2.22 inches, which is 37 per cent of the total amount of water used in irrigation and 28.7 per cent of the amount evaporated from a free-water surface. As an average 33.8 per cent of this amount was lost in the period between irrigation and cultivation.

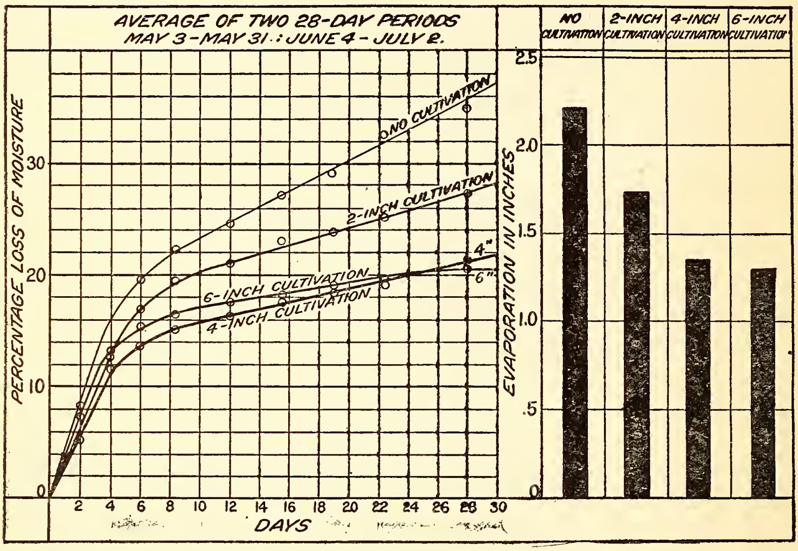

FIG. 21.—Average evaporation losses from tanks cultivated to different depths at Davis, Cal., May 3-31 and June 4 to July 2, 1910.

Of the 2.22 inches lost from the uncultivated surfaces, 21.2 per cent was saved by a 2-inch cultivation, and 39.2 per cent by a 4-inch cultivation. The difference between the 4-inch and the 6-inch cultivation was so small that no attempt is made to draw conclusions. The low percentage of moisture in the soil and the moderate climatic conditions during both periods made a 4-inch cultivation as effective as the 6-inch.

The table following shows the depths in inches and the percentages saved by the different depths of cultivation.

Losses by evaporation from surfaces cultivated to different depths, and by saving due to different depths of cultivation.

Condition of surface.	Loss by evaporation.	Amount saved over free-water surface.		Amount saved over no cultition.		Amount saved over 2-inch cultivation.		Amount saved over 4-inch cultivation.	
	Inches.	*Inches.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*
Free-water surface	7.78								
No cultivation	2.22	5.56	71.5						
2-inch cultivation	1.75	6.03	77.5	0.47	21.3				
4-inch cultivation	1.35	6.43	82.5	.87	39.2	0 40	22.8		
6-inch cultivation	1.31	6.47	83.1	.91	40.9	.44	25.1	0.04	3.0

SUMMARY OF RESULTS AT ALL STATIONS.

Similar experiments were carried on at each of the other stations, but in all cases, save one, rainfall interfered to such an extent that the mulches produced by the different depths of cultivation were completely destroyed. In some instances where the soil was cultivated after each shower the losses from the deeper cultivated soils were greater than from the uncultivated surfaces. This was particularly noticeable where the rainfall came in light showers of 0.5 inch or less every three or four days. Immediately following cultivation an additional loss is observed for one or two days, due to moist soil being exposed. If a cultivation is followed by a shower and then another cultivation it is easy to see that deep cultivation may increase rather than diminish the loss by evaporation.

When evaporation losses alone are considered the small saving at each of these stations seems to discourage rather than encourage cultivation during a season of intermittent rainfall, especially when the rainfall occurs in light, evenly distributed showers.

The evaporation losses from a water surface at each of the several stations for the months of May and June during 1909 and 1910 are given in the following table, which shows the great variation in the losses at the stations where experiments were conducted.

Total and average weekly evaporation losses at the seven different stations.

Stations.	1909		1910		1909–1910.
	Months.	Total loss.	Months.	Total loss.	Average weekly loss.
		Inches.		*Inches.*	*Inches.*
Agricultural College, N. Mex.	May and June [1]	11.13	May and June [1]	12.98	3.02
Caldwell, Idaho	do.[1]	9.81	do.[1]	8.78	2.32
Davis, Cal	do.[1]	9.41	do.[1]	7.73	2.14
Reno, Nev	do.[1]	8.49		11.03	2.44
Sunnyside, Wash	May	7.09	May 21–June 15	7.25	1.90
Williston, N. Dak			May	5.21	1.86
Bozeman, Mont	June	4.26	May and June	4.51	1.10

[1] Average for two months.

The average weekly losses for the several stations are shown graphically in figure 22.

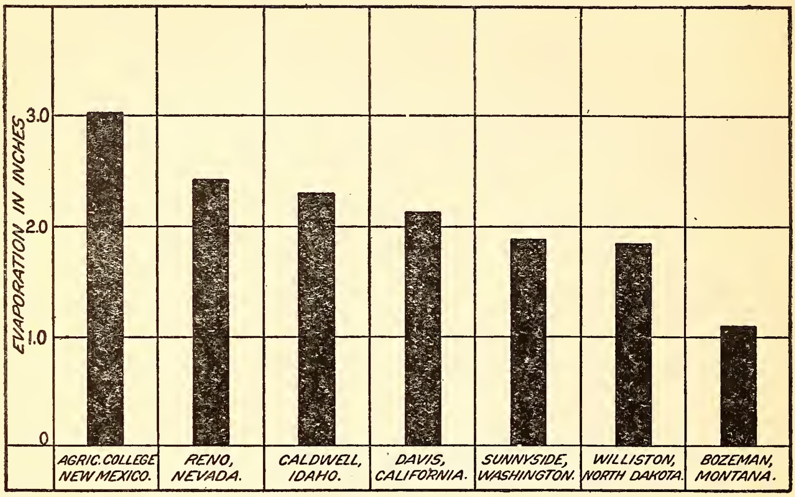

FIG. 22.—Average weekly evaporation from free-water surface at Agricultural College, N. Mex.; Reno, Nev.; Caldwell, Idaho; Davis, Cal.: Sunnyside, Wash.; Williston, N. Dak.; and Bozeman, Mont.

In order to illustrate the effect of temperature and wind velocities on evaporation, the mean daily temperatures, wind velocities, and

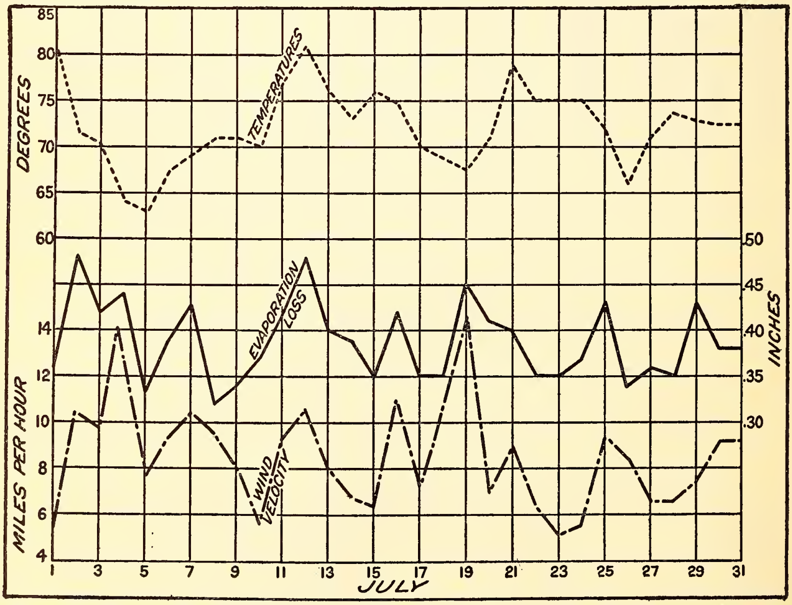

FIG. 23.—Mean temperatures, average wind velocities, and evaporation losses from a free-water surface at Davis, Cal., July 1909.

evaporation losses have been platted from the records taken at the California station during July, 1909. (Fig. 23.)

Although no attempt is made to establish a relation between temperature, wind velocity, and evaporation, it is interesting to notice their general influence by the uniform variation in the curves.

This and the results obtained at the other stations show the wind velocity to be the controlling factor. The temperature influence seems to overbalance that of the wind only when the latter is at a minimum. For instance, July 10, 22, and 23, when the wind velocities were at a minimum, the atmospheric temperatures were comparatively high and moderate evaporation losses are recorded.

EFFECTS OF TEMPERATURE AND WIND VELOCITY.

In the study of evaporation from a free-water surface the controlling factors are the temperature of the water surface, the vapor pressure at the water temperature and dew point, and the wind velocity

The following results were obtained from experiments carried on in California at several widely distributed stations during 1904–5, in a study of the influence of the temperature of the water surface on evaporation.

Average temperature of water and evaporation therefrom.

Average temperature of water surface.	Daily evaporation.
°*F.*	*Inch.*
53.4	0.09
61.3	.19
73.5	.36
80.4	.48
88.7	.60

Although this shows no definite ratio existing between the temperature of the water surface and the evaporation, it gives a general idea of the enormous influence which the temperature of the water exerts. As the temperature of the water depends directly upon and follows very closely the atmospheric temperatures, the latter must be recognized as one of the controlling factors in evaporation losses.

An evaporation tank for the measurement of evaporation from a water surface was installed at each of the several stations as an auxiliary to the soil tanks. These tanks had an inside diameter of 22 inches and a depth of 28 inches. The upper half of each was double-jacketed, the idea being to fill the annular space in the jacket with water and prevent the temperature of the surrounding soil from influencing the temperature of the water in the upper half of the evaporation tank proper. These tanks were set flush with the ground surface in an unobstructed spot and readings were taken daily or semiweekly. The measurements were generally taken with a hook gage, and the losses computed in inches.

Figure 24 is a similar diagram in which the mean hourly observations of temperature, wind velocity, and evaporation are platted for a period of 24 hours and shows more in detail the same general features that are shown in figure 23.

As an aid in measuring the evaporation from water surface, during the experiments of 1910 the station at Davis, Cal., was fortunate in having at its disposal an evaporimeter designed and built by E. J. Hoff of this office. A sketch of the essential features of this instrument is shown in figure 25. A is a double-jacketed evaporation tank, connected to a smaller cylindrical tank B, 7 inches in diameter, by a 1-inch galvanized-iron water pipe. The water in the two tanks obviously stands at the same height. The float D resting in tank B, is connected by a fine brass wire to the marking arm GH of the recording apparatus. This arm is pivoted at the point F to support K, the distance FG being just one-tenth of the distance FH. A light counterweight T serves to keep the wire taut, but is heavy enough to prevent the float from following the changes in the water level, in tank A, due to rainfall or evaporation. The record sheet is fastened to the circular drum N which is pivoted at O and connected with the

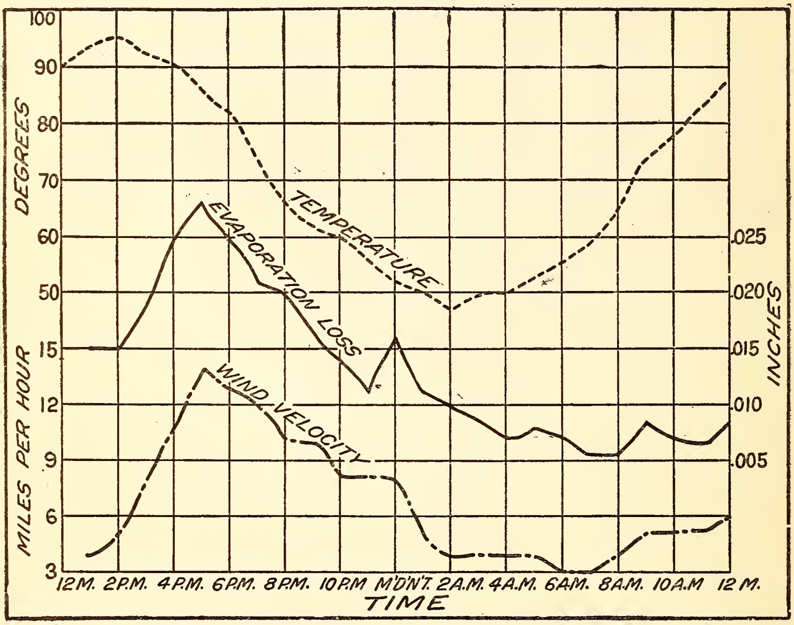

FIG. 24.—Mean hourly temperatures, wind velocities, and evaporation losses from free-water surface from noon July 12 till noon July 13, 1910, at Davis, Cal.

clockwork P by means of a series of fine gears. The cylinder N makes one complete revolution every 12 hours. A wire frame RS connected to a ratchet on the clock works brings the arm GH against the paper once every five minutes, making a dotted instead of a solid line, which prevents the friction of the pen H on the paper from interfering with the gradual lowering of the float as the water lowers in tank B.

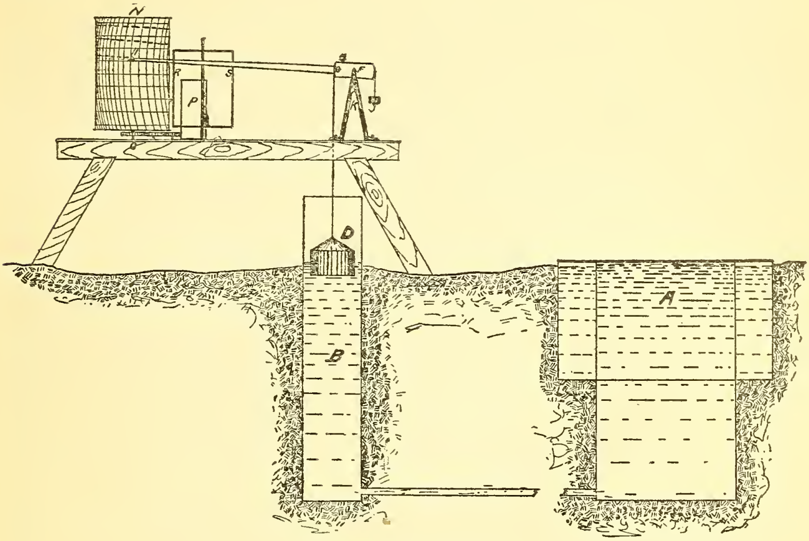

FIG. 25.—Evaporimeter.

This instrument was in constant use for one whole season and gave excellent satisfaction. With it the loss of any period of the day could be read to one-thousandth of an inch. The losses shown on the record sheet are 10 times the actual evaporation loss. A sample record taken from the instrument is shown in figure 26.

Hourly observations were made at several stations for a period of 24 hours, showing the daily range of temperatures, wind velocities, humidities, and evaporation. Those for Davis, Cal., and Caldwell, Idaho, are shown in the tables following.

Hourly temperatures of air, soil, and water at Caldwell, Idaho, 6 a. m., Aug. 28 to 6 a. m., Aug. 29, 1909.

Time.	Temperature of air.			Temperature of soil.					Temperature of water.		
	Five feet above ground.	At surface in the sun.	At surface in shade.	Three inches below surface in tank.	Six inches below surface in tank.	½-inch below surface near tank.	Three inches below surface near tank.	Six inches below surface near tank.	½-inch below surface	Three inches below surface.	Six inches below surface.
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
6 a. m.	46	......	44	58½	64½	48	63	72½	56	57½	58
7 a. m.	44	47	45	58½	64	48	62½	72	57½	57½	57¾
8 a. m.	58	62	62	58½	64	57	62½	72	58	58	58
9 a. m.	62	70	64	61	64	70	64	71	58	58	58
10 a. m.	68	83	71	63	64	83	66½	70½	59¼	59	58¾
11 a. m.	73½	85	79	66	64½	94	70	70½	61	60½	60¼
12 m.	76½	90	83	69½	65½	101½	75	71½	64	63	61¾
1 p. m.	81	97	86	72½	67	106½	79½	72½	68½	67	64½
2 p. m.	83	102	88	74½	68	109	82	73	69½	68½	66
3 p. m.	85	104	89	77	69½	109	84½	74	71½	69¾	67½
4 p. m.	85½	101	88	77	71	105	85½	75½	70¾	70½	68¾
5 p. m.	85	98	88	77	72	100	86	76½	71	70	69¼
6 p. m.	85	92	85	77½	72½	93	85½	77½	70½	70	69¼
7 p. m.	80	76	75	75½	73½	78	84	78	69	68½	68
8 p. m.	78½	......	68	75	73	72	82	78½	68	67½	67
9 p. m.	72½	......	63	72	72½	66	78½	78½	66	65¼	65
10 p. m.	67	......	63	70	72	61	76½	78	64½	64½	64½
11 p. m.	66½	......	62	69	71½	61	74½	78	63½	63½	63½
12 p. m.	63½	......	60	68	70½	60	73	77	63	63	63
1 a. m.	62	......	60	65½	69½	60	71½	76½	62½	62½	62½
2 a. m.	60	......	57	65½	69	59	70½	76	62½	62½	62½
3 a. m.	58½	......	58	64	68½	59	69½	75½	61¾	61¾	61¾
4 a. m.	60	......	59	64	67½	59	68½	75	61½	61½	61½
5 a. m.	53½	......	52	63½	67	57	68	74½	61	61	61
6 a. m.	55	......	54	63	66½	57	67	74	61	61	61
Mean.	68⅖	85⅕	$72\frac{9}{10}$	68⅖	$68\frac{3}{10}$	$74\frac{1}{10}$	74⅘	$74\frac{7}{10}$	64.0	59⅗	63⅛
Range.	41½	57.0	45.0	19.0	9½	58½	23½	8.0	15½	13.0	11½

Hourly temperatures of air, soil, and water, humidity, evaporation from free-water surface and velocity of wind at Davis, Cal., noon July 12 to noon July 13, 1910.

Time.	Temperature of air.	Temperature of soil.			Temperature of water.			Humidity.	Evaporation.	Wind velocity.
		½ inch below surface.	3 inches below surface.	6 inches below surface.	½ inch below surface.	3 inches below surface.	6 inches below surface.			
	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	*Per ct.*	*Inch.*	*Miles.*
12 m.	90	118	88	86½	84	83	82½	....	....	....
1 p. m.	94	120	89½	87¼	87	86	85½	29.0	0.015	4.0
2 p. m.	96	122	91	88¾	88½	88	87	27.0	.015	5.0
3 p. m.	93	118	93	90¼	90	89	89	28.0	.020	8.0
4 p. m.	91½	114	94½	92	89½	89	89	32.0	.025	11.0
5 p. m.	86	106	95	93	88	88	88	36.0	.027	14.0
6 p. m.	80½	96	95	93	87	87	87½	41.0	.025	13.0
7 p. m.	72	82	94½	93¼	86	86	86	46.0	.021	12.0
8 p. m.	67	76	92½	92½	84	83	83	61.0	.020	10.0
9 p. m.	62	73	91	91¼	81	80	80	66.0	.017	10.0
10 p. m.	60	68	89¼	90	77	76	75	70.0	.014	8.0
11 p. m.	56	66	87¼	88¼	75	74	73½	74.0	.011	8.0
12 midnight	54	63	86	87	74	73	73	75.5	.016	8.0
1 a. m.	51	60	84½	86¼	73½	72½	72½	77.0	.011	5.0
2 a. m.	48½	58	83	85	72½	72	72	82.0	.010	4.0
3 a. m.	50	60	82½	84¼	72	72	72	86.0	.008	4.0
4 a. m.	50	60	81¾	83½	71½	71	71	88.5	.007	4.0
5 a. m.	53	62	81¼	83¼	71	70½	70	81.5	.008	4.0
6 a. m.	57	65	81	82½	71	69	69	72.0	.007	3.0
7 a. m.	59	70	80½	82	70½	68	68	70.0	.006	3.0
8 a. m.	65	75	79¼	81	70½	69½	68½	65.0	.006	4.0
9 a. m.	75	88	80	81	74	73	72	62.0	.008	5.0
10 a. m.	79	92	81½	82¼	76	75	74	50.0	.007	5.0
11 a. m.	83	102	83	83	73	78	76	42.0	.007	5.0
12 noon	87	108	84½	83½	80	79	78	41.0	.008	6.0
Mean.	70⅖	$84\frac{9}{10}$	86⅖	86⅘	$78\frac{9}{10}$	$78\frac{1}{10}$	$77\frac{7}{10}$	58.4	.0134	6.8
Range.	47½	64	15¾	12¼	19½	21	21	61.5	.021	10.0

It is a well-known fact that the temperature of soil and water surfaces directly influence the evaporation from their surfaces, these temperatures being directly influenced by the temperature of the air. From these tables it will be seen that while the atmospheric temperatures range from 40° to 50° F. during the 24 hours that the temperature of the soil surface varies from 60° to 70° F. and at a depth of 3 to 6 inches the variation averages but 17° and 10°, respectively. The surface temperature follows very closely that of the air, while at a depth of 6 inches the maximum is not reached until 4 to 5 hours later, this of course depending upon the compactness and moisture content of the soil.

The water temperatures show but little variations in depth up to 6 inches and a range of 40° to 50° in the atmosphere produces but 15° to 20° variation in the water. The following diagram, figure 27, prepared from the observations of July 12 and 13, 1910, at Davis, shows the hourly variation in temperature at the different depths for both soil and water.

In some localities covered by these experiments maximum temperatures of the surface soil often

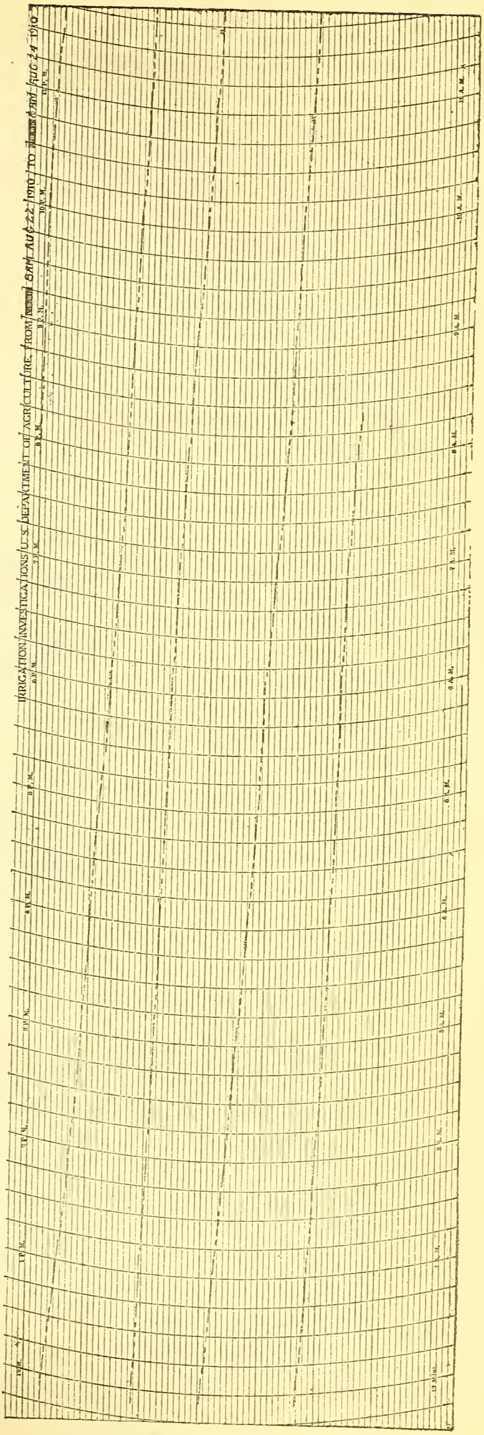

FIG. 26.—Evaporimeter sheet.

reached 120° to 130° F., whereas under the same conditions the temperature of the water surface varies from 80° to 90°. Remembering the influence of water temperatures on evaporation it is easily seen why the loss from a saturated soil surface may exceed that from a water surface. These temperatures given above are for dry soils and the temperature of saturated soils will naturally be much lower.

The results thus far obtained show but little difference in the temperatures of cultivated and uncultivated soils. Where these temperatures have been recorded the uncultivated soils average at a depth of 6 inches from 1° to 2° F. higher than the cultivated.

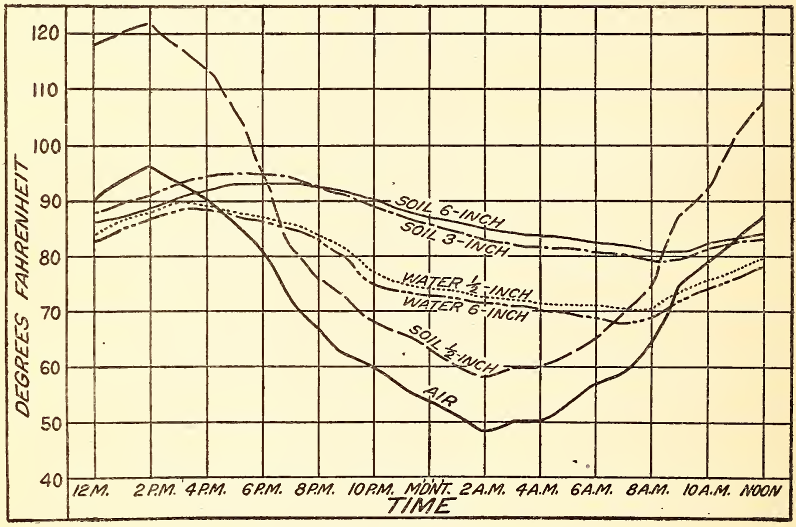

Fig. 27.—Temperature of air and of soil and water at different depths from noon July 12 to noon July 13, 1910, at Davis, Cal.

GENERAL CONCLUSIONS.

The uniform results obtained in the experiment on soil mulches in preventing evaporation losses clearly demonstrate that if in field practice irrigation water could be placed at a depth of 6 to 9 inches below the soil surface but little moisture would be lost by evaporation. This in itself points toward the use of fewer and deeper furrows.

The results thus far obtained show that the saving of moisture increases with the depth of application. Practical considerations, however, limit the depth. Under conditions such as exist throughout the arid region this practical limit lies, it is believed, somewhere between 6 and 9 inches.

Considerations other than the saving of moisture often determine the mode of applying water. Attention is called to the chief of these.

(1) The available water supply and the probable period between irrigations. In the case of a very limited supply of water or where heavy orchard irrigation is practiced at long intervals, fewer and deeper furrows are of greatest benefit. The water is placed well into the soil and during the long period of application only a small per cent of the surface soil is wet, thus lessening the heavy evaporation losses which take place in the period between irrigation and cultivation. Cultivation may likewise be practiced almost immediately after irrigation and the losses further reduced.

(2) The character of the soil. It has been seen that heavy clay soils tend to hold the moisture near the surface, owing to their imperviousness. This type of soil favors capillary movement, and heavy evaporation losses are the result. In such cases deep furrow irrigation not only diminishes the losses but checks any tendency toward the formation of hardpan.

(3) The kind of crop irrigated. Some plants are shallow-rooted and if water is placed deep into the soil the roots are not only destroyed in making the deep furrows, but the water is placed beyond the feeding zone of the plants. On the other hand, in deep soil planted to deep-rooted crops, shallow irrigation would lure the fibrous rootlets to the surface of the soil where they would be destroyed by cultivation or drought.

The advantages and disadvantages of shallow and deep irrigation are discussed in detail in a bulletin of this office.[1] A summary of the advantages and disadvantages of shallow and deep irrigation is given below. In this summary shallow irrigation refers to the application of water on the surface or in furrows not exceeding 3 inches in depth, while deep irrigation refers to irrigation in furrows 6 to 12 inches in depth.

In general, it may be stated that wherever the soil and the crop will permit the water should be applied in deep furrows rather than by flooding; that one deep, heavy irrigation is preferable to numerous lighter irrigations, providing the crop is deep-rooted; that cultivation should be practiced as early as possible after irrigation; and that deep and frequent cultivation prevents evaporation and aerates the soil.

In the general practice of deep furrow irrigation, cultivation approximating the depth of the furrows naturally follows. In flooding and shallow-furrow irrigation, where a large percentage of the surface soil is wet, and the cultivation of the entire ground surface is necessary, the question of deep versus shallow cultivation becomes important. If one considers only the actual saving of moisture apart from other benefits produced by cultivation a determination could be reached readily by comparing the value of the water saved with the extra cost of deep cultivation. In making such a determination the controlling factors would be the character of the soil and the value of the water supply. In some of the heavier adobe and gumbo soils, deep cultivation is next to impossible, especially within a reasonable period after irrigation or heavy rainfall, while in lighter sandy soils cultivation to a depth of 8 to 10 inches is often practiced and not considered excessive.

---

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 177.

In many cases the actual saving of water is one of the least important features of deep mulches. Prevention of the formation of hardpan, the decreasing of the waste by run-off during heavy rainfall, the prevention of valuable salts and plant food in solution from being drawn to the surface and carried away by surface drainage during excessive rainfall, the deep penetration and more thorough circulation of air and water through the soil, the increased water-holding capacity of the soil, and the deep-rootedness of plants and trees are additional reasons for deep and thorough cultivation.

The fertility of soils depends in a great measure upon the percentage of available nitrates, sulphates, and phosphates contained in them. In cases of heavy evaporation losses the capillary rise of water[1] carries the salts held in solution to the surface of the soil and when the water evaporates the salts are left above the feeding zone of the plant roots and thus deprived of their useful function. Analyses of the first inch of mulched and unmulched soils, made by Prof. F. H. King, show that the mulched surfaces contained a much smaller percentage of nitrates, sulphates, and phosphates and prove that a much smaller percentage of these valuable salts had been drawn from the lower strata of soil by capillarity. Again, if the surface soil is well mulched the pore space may approach 50 per cent of the total volume and nearly 2 inches of rainfall may be stored in 4 inches of soil. The water so stored dissolves the salts that have been carried to the surface and carries them back in solution to the root zone of the plants. In the case of an unmulched soil, the pore space is reduced and when heavy rains occur the salts are carried away by surface drainage.[2]

The depth of the mulch determines to a great extent the capacity of the soil for air and water. The soil is thoroughly aerated by the deep cultivation necessary to produce deep mulches, and its loose condition allows a much freer circulation of air and water, carrying with them oxygen and the soluble salts. Root growth follows the supply of moisture and plant food, and if these are placed deep into the soil deep-rooted plants will be the result. The orange in its natural state is said to be a shallow-rooted tree and the tendency of the roots is to spread out near the surface. This tendency is encouraged through the rainy season in California, when the surface is kept moist by frequent rains and when the evaporation is reduced to a minimum by cool weather, fogs, and rain. It is doubtful, however, if the roots found in the upper 6 inches of soil are of any benefit to the tree, for while they may collect both food and moisture during the three months of the rainy season the excessive evaporation during a period of 30 to 45 days between irrigations in summer is quite certain to wither and kill the fibrous rootlets. It is deemed better for this reason to prevent the extension of the roots through the top layer of soil by frequent deep cultivations.

---

[1] U. S. Dept. Agr., Bureau of Soils Bul. 38.

[2] "Some Results of Investigations in Soil Management," U. S. Dept. Agr. Yearbook, 1903, pp. 159-174.

Deep cultivation and deep mulches tend not only to prevent the formation of hardpan, but do much to destroy that already formed. In some orchards long-continued, shallow cultivation of the soil to the same depth has created a compact layer of soil often several inches in depth. This limits the circulation of air and water through the soil and in some cases has been known to cause the total loss of orchards. Such a layer may be prevented and, if already formed, can be broken up by deeper cultivation, in which the depth is varied from year to year.

THIS PUBLICATION may be procured from the Superintendent of Documents, Government Printing Office Washington, D. C., at 15 cents per copy